GEOLOGICAL AND GEOTHERMAL INVESTIGATIONS
FOR HCMM-DERIVED DATA

Final Report NAS5-24232

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by

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June 1981

REMOTE SENSING LABORATORY
SCHOOL OF EARTH SCIENCES

STANFORD UNIVERSITY • STANFORD, CALIFORNIA

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16. Abstract
(1)This study relates an attempt to match the HCMM- & U2HCMR-derived temperature data over two testsites (of very local size) to similar data collected in the field at nearly the same times. Considerable logistical problems were encountered. The results indicate that HCMM investigations (using resolution cells of 500m ,or so) are best conducted with areally-extensive sites, rather than point observations. The DAY-VIS imagery is of excellent quality, and has considerable usefulness for GEOLOGY ,especially for structural (lineament) studies. For these purposes one does not need the Day-Night registered imagery, except that as a single product,not to be used for further calculations, the DELTA-T imagery is most useful,again for structural geology.Our attempts to register the ground-observed temps. (even for 0.5 sq.mile targets) were unsuccessful, due to the excessive pixel-to-pixel noise on the HCMM data.

(2) Several computer models were explored, and related to changing of the values of ~~thermal~~ parameters, with observed data. Unless quite complex models,with many parameters which can only be observed (perhaps not even measured!) under remote sensing conditions (e.g. roughness,wind shear etc.) the model outputs do not match the observed data.Empirical relationships may be most readily studied.

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STANFORD HCMM FIELD EXPERIMENT-- OBJECTIVES	RESULTS
A. LOCAL CALIBRATION SITES (Determine Met. Data)	
1. GROUND STATIONS (2)	
a. "Sand Box"Expt. (Known Thermal Inertia)	MATCH WITHIN 1.3^{o}C RMS
b. Soil probes	MATCH WITHIN [illegible]-11^{o}C RMS
B. DEVELOP MODELS USING FIELD DATA - "SANDBOX"	
1. WATSON program	MATCH WITHIN 5.5^{o}C
2. CSIROTEMP program	MATCH WITHIN 1.3^{o}C
C. RELATE P3/ MMS OVERFLIGHT TEMPS TO GROUND SITES	P3-DAY BB REVERSED -NIGHT BB's TOO WIDEL[Y] SPACED + CALIBRATIONS AMBIGUOUS
D. RELATE U-2 OVERFLIGHT (HCMR) TEMPS TO FIELD SITES.	ADJOINING WATER PIXELS 0.4^{o} APART . SHOW 9.4^{o}
E. RELATE HCMM TEMPS TO FIELD SITES	A0034 WRONG REG. TAPE RECD. 87 WRONG REG. TAPE RECD. 226 REGD TAPE RECD LAST WEEK
F. USE HCMM REGISTERED DATA FOR ROCK/SOIL DETERMINATION WITH LANDSAT	NO ACTION
	HOWEVER: USE OF DAY VIS + NIGHT IR ON THE COLOR TV DISPLAY YIELDS SIGNIFICANT DATA ON GEOLOGICAL STRUCTURE OF A REGIONAL SCALE.

I. INTRODUCTION

The understanding and interpretation of thermal infrared data has continued to be a significant goal of several research organizations throughout the world. The Stanford Remote Sensing Laboratory, one of these groups, is keenly aware of the difficulties that still exist in the determination of thermal parameters at the ground-air interface. The relationship of these parameters to thermal mapping employing techniques was a major aspect of this study.

The work performed under this contract attempts to assess the type and complexity of the thermal models required for rock and soil parameter discrimination employing aircraft and satellite (HCMM) thermal infrared data. A field measurement program was performed to compare the modelling results and assess their accuracy. This field data was then used to establish local calibration sites to which the aircraft and satellite data could be related.

The ultimate objective of the study was to establish the feasibility and value of thermal infrared data in the delineation of hydrothermally altered areas in the Yerington Nevada test site. The spectral filtering of the current Landsat system does not permit the separation of ferric iron hydrothermal alteration from ferric iron coatings on unaltered volcanic rocks. However, the marked density differences between the hydrothermally altered and unaltered rocks should produce, after the proper modelling of surface me[illegible]logical variables, a resolvable difference in the thermal property of these units. The study, therefore investigated the combined value of Landsat and HCMM data in the discrimination

of hydrothermal alteration zones at Yerington Nevada.

II. INITIAL FIELD STUDY — YERINGTON NEVADA (AUGUST 8-9, 1977)

Field measurements coincident with U-2 and M^2S data acquisition were made August 8-9, 1977 at two sites near Yerington, Nevada. The mission was designed to investigate the relationship of thermal parameters to rock density for mineral exploration, and to further test the validity of thermal modelling by relating overflight data over Yerington to the two local calibration sites.

In order to meet these objectives, many types of data were collected every 36 minutes over a 24 hour period. Temperature of the soil surface was recorded using thermocouples, and PRT-4 and PRT-5 radiation thermometers. The field team also recorded soil temperatures at various depths, net radiation, and short-wavelength radiant flux incident upon the ground surface. Exotech, (Landsat band), radiometers were employed to measure surface albedo. Because the thermal properties, inertia $(K\rho c)^{\frac{1}{2}}$ and diffusivity $(K/\rho c)$, of the surface materials are very dependent on the local meteorology, several additional measurements were made. Data recorded to describe the local meteorological conditions included the air temperature just above the soil-air interface and approximately one meter above the soil, the near-surface humidity, wind velocity, and the percent cloud cover. Soil moisture samples were taken at depths corresponding to the soil temperature probes.

Additional calibration measurements were made at a leach pond near the Anaconda Dump Station. Two recording thermometers were used to record

the subsurface water temperature continuously during the 24 hour data collection period.

A. FIELD TEST SITES

1. Anaconda Dump Site

The main data recording station was located on the Anaconda Company's waste rock dump north of the Yerington open-pit mine near a level access road (Plate 1). The site is bordered by waste rock mounds about 8 feet high, and on the south side of the site there is a cliff facing the leach ponds to the north (plates 2 and 3). The station was located on a uniformly flat surface of crushed rock tailings. No vegetation was visible on or near the dump site.

Three sets of temperature probes were monitored at this station. One set involved a well insulated wooden box filled with ottawa sand with known thermal parameters. Temperature measurements of the surface and at various depths into the sand were recorded during the mission. Two sets of temperature probes were placed beneath the ground surface. One set was encased in a "spike" metal tube containing temperature probes at different depths. The other set of temperature probes were contained in a plastic sewer pipe. These probes were insulated from each other with cotton gauze.

PRT-5 measurements were made to determine the surface temperatures at the station. The field team also recorded the air temperature, near surface humidity, wind velocity, cloud cover, net radiation, and radiant flux incident to the ground surface for the entire field station. Albedo measurements were taken with Exotech (Landsat band) radiometers before and during these experiments. Soil samples were also collected at depths corresponding to the temperature probes.

Two sets of water temperature data were continuously recorded at the leach pond northeast of the Anaconda dump site (plate 4). One probe, labeled "A", was placed 10.2 cm from the bottom of the pond about 3—4.5 meters away from a drainage pipe where the water flow was nearly constant. The other probe was placed 12.7 cm from the pond bottom in a calmer area away from any constant flow. Both probes were mounted in separate wood blocks and both were placed about a meter from shore.

2. <u>MacArthur Station</u>

The second recording station was located at the Anaconda Company's copper prospect on a wash covered with a sparse cover of low vegetation, (Figure 2). Small hills were located on two sides of the site.

Data similar to that of the Anaconda Dump station was taken at this station. A sewer pipe containing insulated temperature probes at various depths was used to collect one set of soil temperature profile data. Another set of soil temperature profile data was collected by simply placing probes into the ground at different depths. The air temperature, wind velocity, percent cloud cover, surface temperature, and incident short-wavelength radiant flux were measured every 36 minutes. Albedo measurements were also made with the Exotech units. Soil samples were collected in order to determine the moisture content profile of the soil.

B. RESULTS

1. <u>Soil Temperature Measurements</u>

Temperature profiles for four different times during the 24 hour measurement period are found as Figures 3 — 7. The original data used

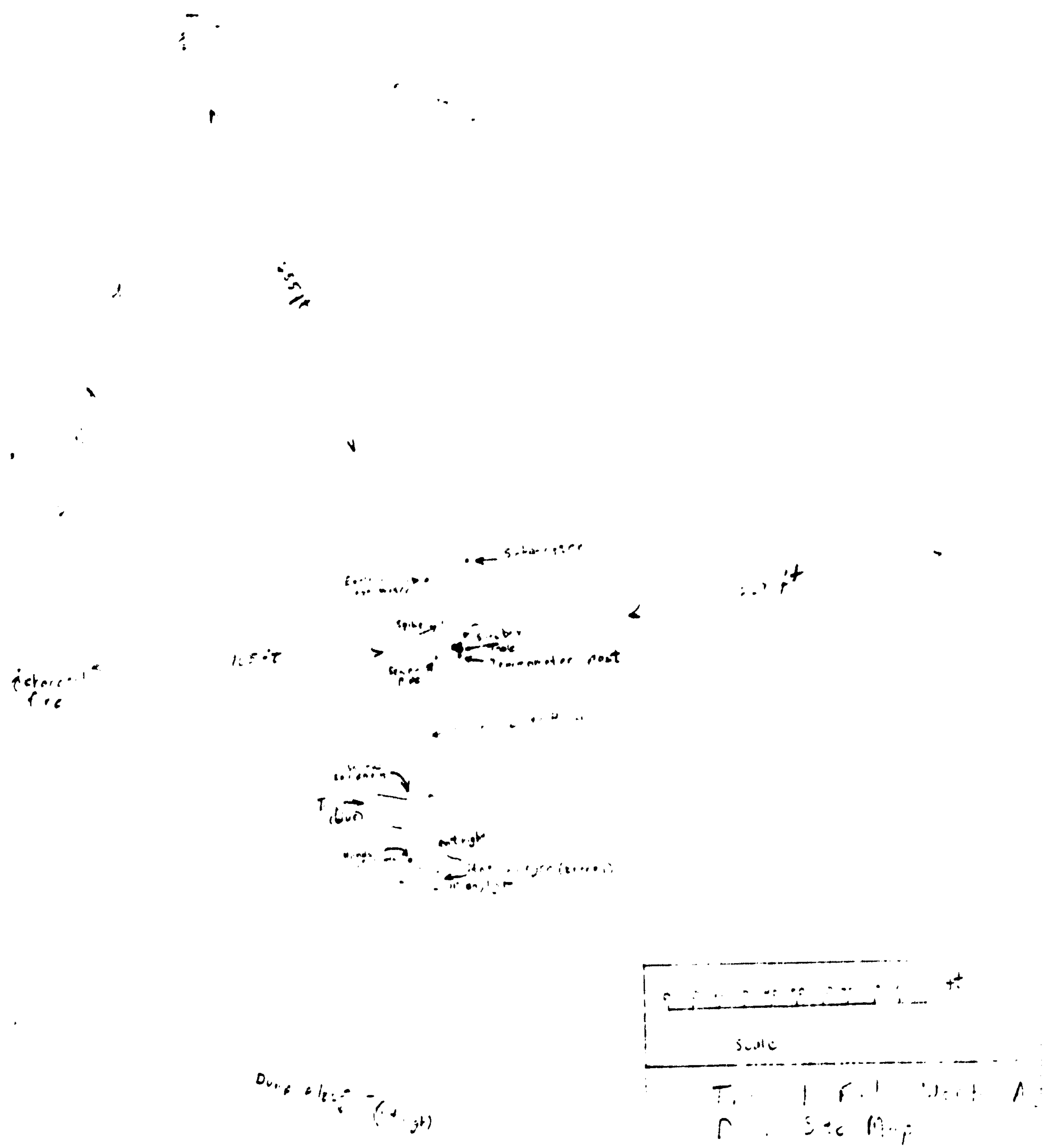
Scale

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PLATE 1a PREPARATIONS FOR THE SANDBOX EXPERIMENT

THE PI PREPARING THE FIELD SITE FOR THE TEMPERATURE PROBES

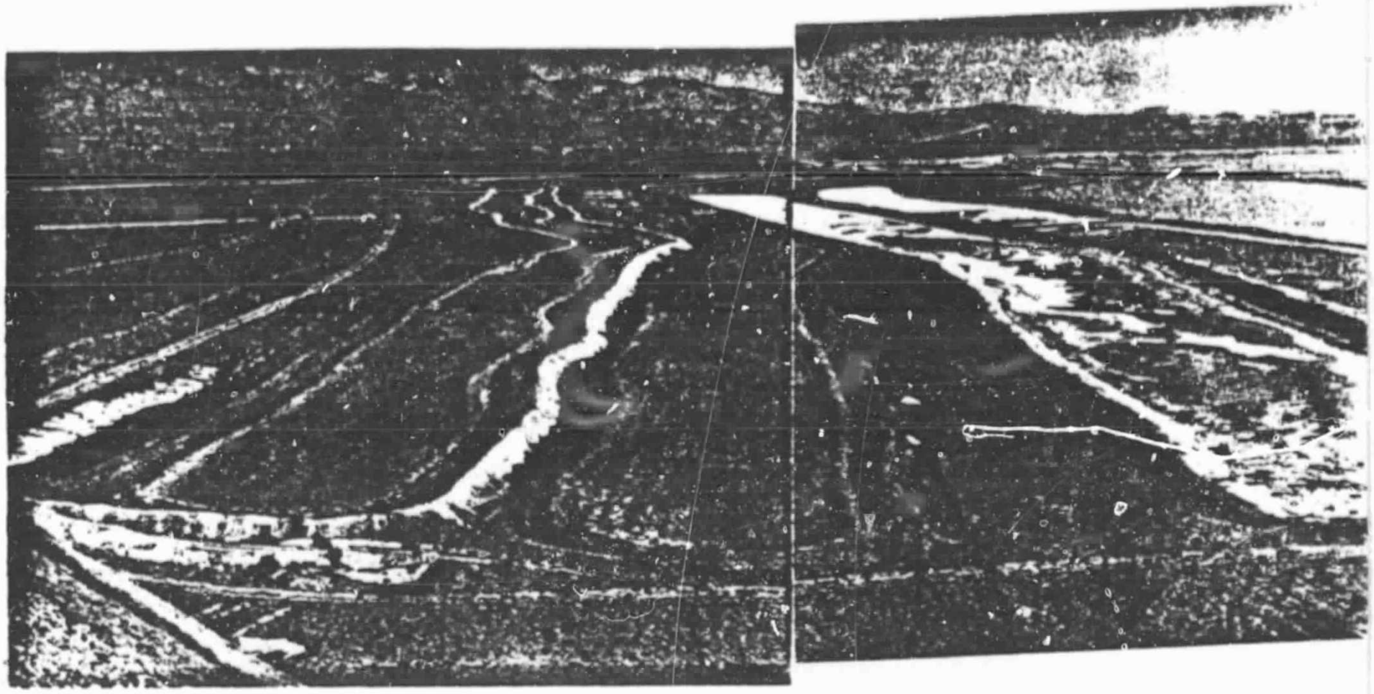

PLATE 2. NNW AND N VIEWS FROM THE "ANACONDA" DUMP SITE LOOKING ON TO THE LEACH PONDS WITH THE RECORDING THERMOMETERS

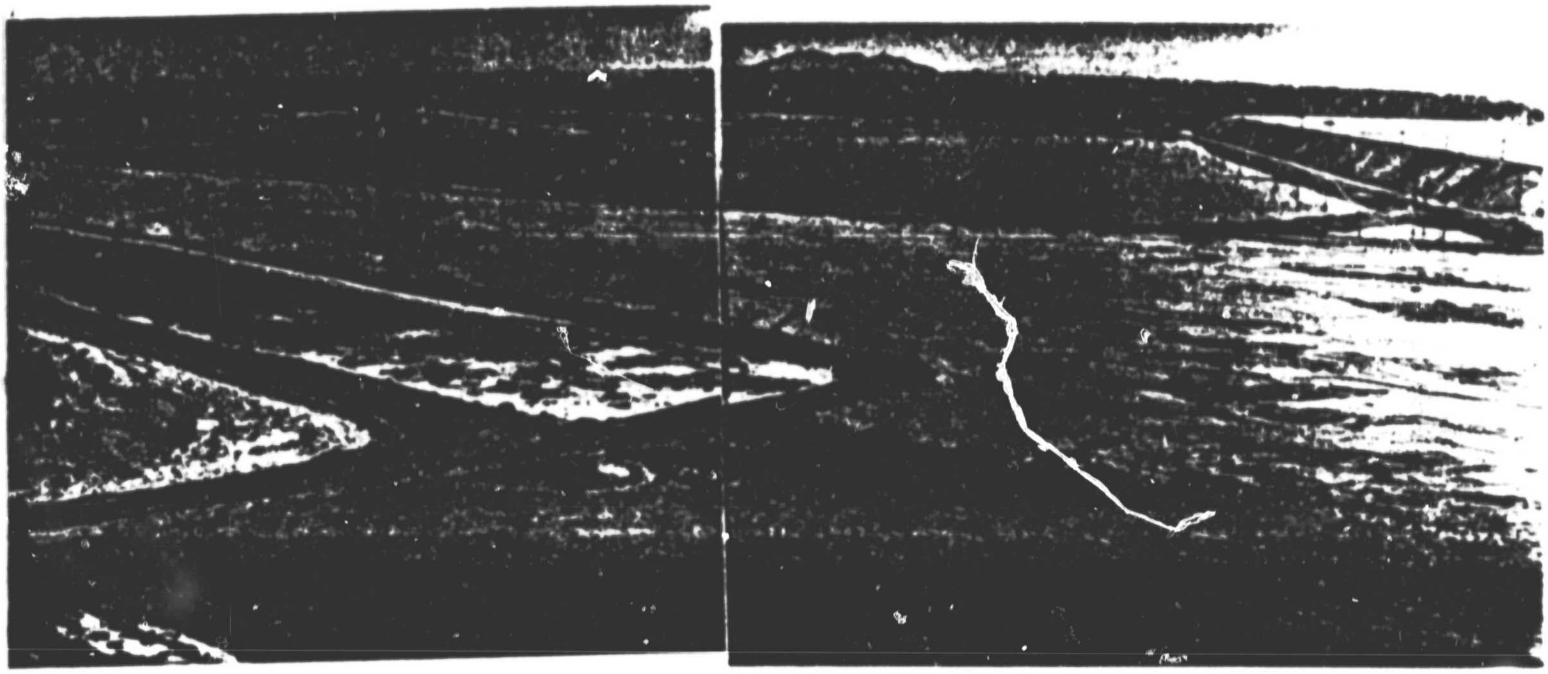

Plate 3a. VIEW E & NE FROM THE ANACONDA DUMP SITE. THIS VIEW IS A CONTINUATION OF THAT OF THE PREVIOUS PLATE (2).

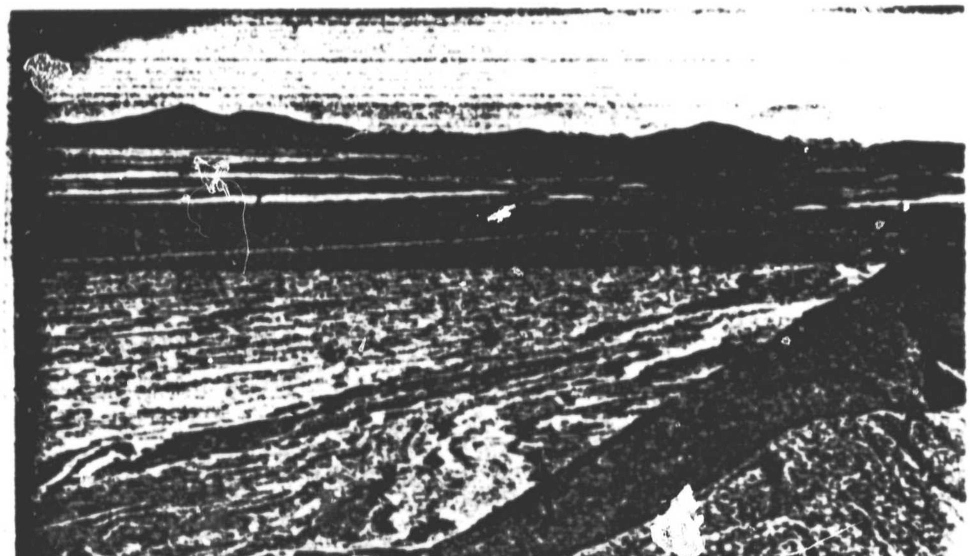

Plate 3b. VIEW SE FROM THE ANACONDA DUMP SITE

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Plate 4a VIEW N ON ROAD TO LEACH POND WITH THE RECORDING THERMOMETERS (WEST OF PHOTO)

Plate 4b. LOOKING TOWARDS RECORDING THERMOMETER STATION "B" AT THE LEACH POND.

for the graphs are in Appendix 1. The curves found for each set of temperature probes are more easily described by modelling the temperature profile as:

$\Delta T' = \Delta T\, e^{-D/DD}$ where $\Delta T'$ = temperature change at damping depth

ΔT = temperature change

D = depth

DD = damping depth

Thus the depth at which $\Delta T' = 1/e\Delta T$ is the damping depth. The damping depths and temperature variations for the soil at each set temperature probe site are tabulated in Table 1.

The two graphs depicting the temperature profiles at the Macarthur site show cooler temperatures for the soil as depth increases. This is a typical summer trend showing the effects of the previous cooling cycle.

The damping depths are tabulated for each soil site. Both the surface and a depth just below it are used to determine the maximum change in temperature ΔT (maximum temperature - minimum temperature) during the 24 hour period. Results using the surface temperatures are usually better to use. However, since the validity of the surface temperature for the sand box is doubtful, a near surface depth was also used. $\Delta T'$ is then calculated where $\Delta T' = 1/e\Delta T$. By inspecting Figures 3—7, one can determine the damping depth by finding the depth where ΔT for that depth is equal to the calculated $\Delta T'$ for the surface or near surface depth.

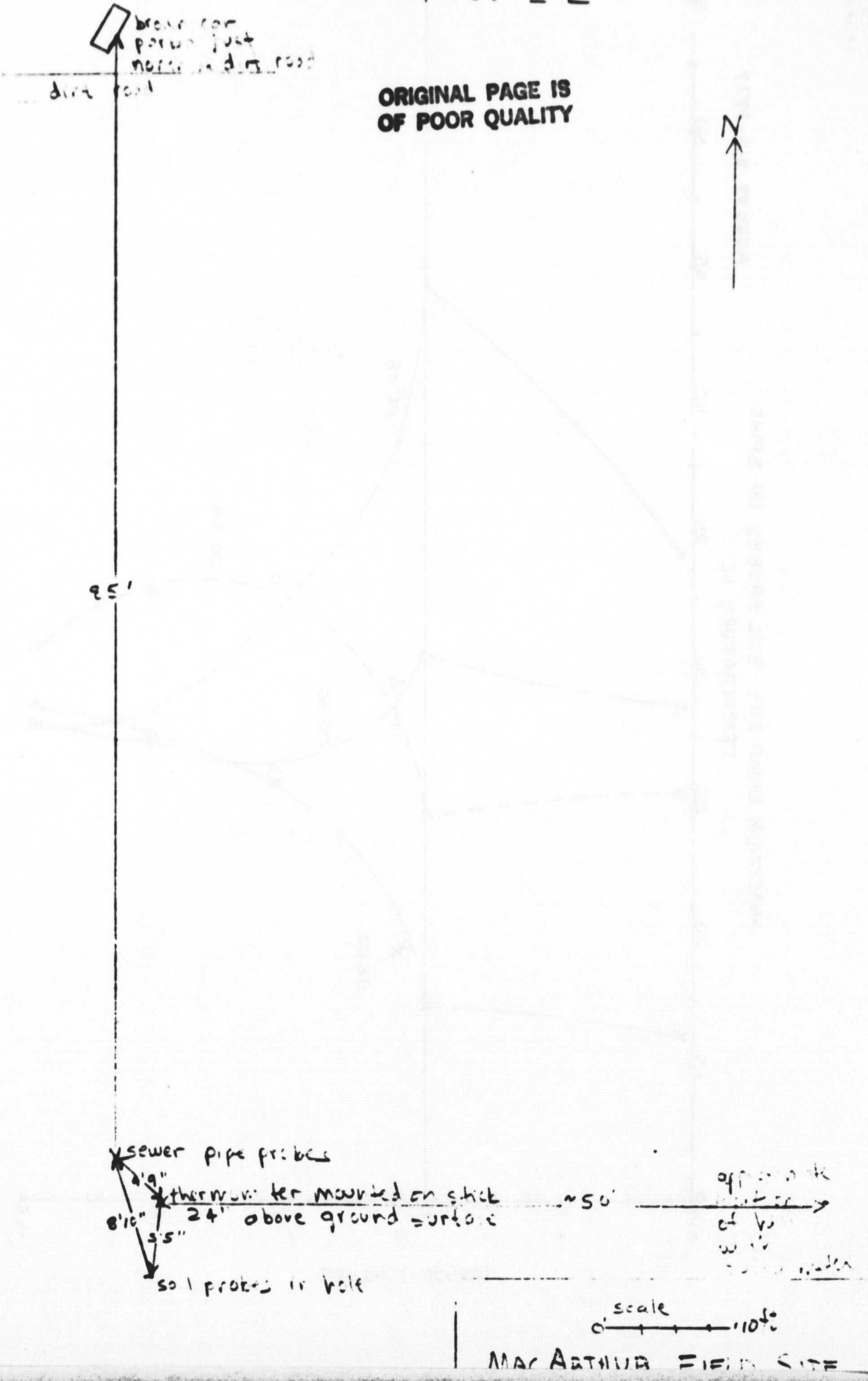
The temperature changes during the 24 hour period are shown for each soil site at 14.5" and 30" below the surface. The sand box and spike did not sense temperatures 30" below the surface.

TABLE 1

Damping Depths of Measured Soils 8/77

Site	Depth Used for ΔT	Area Measured	Maximum Temperature °C	Minimum Temperature °C	ΔT °C	ΔT' °C	Damping Depth (DD) (inches)	ΔT at 14.5" Depth °C	ΔT at 30" Depth °C
Anaconda Dump Site	Surface	Sand Box	33.2	5.2	28.0	10.3	2.5	0.4	---
	0.5"	Sand Box	43.3	12.6	30.7	11.3	2.0		
	Surface	Spike	44.3	17.3	27.0	9.9	3.5	4.0	---
	1.0"	Spike	39.5	19.4	20.1	7.4	5.0		
	Surface	Sewer Pipe	44.3	17.3	27.0	9.9	3.0	1.8	0.3
	1.0"	Sewer Pipe	39.6	18.6	21.0	7.7	3.5		
MacArthur Site	Surface	Sewer Pipe	> 43.3	16.2	> 27.1	10.0	4.0	1.5	1.5
	1.0"	Sewer Pipe	40.0	19.0	21.0	7.7	5.0		
	Surface	Hole	> 43.3	15.8	27.5	10.1	3.5	1.5	0.3
	0.5"	Hole	46.7	16.7	30.0	11.0	3.0		

FIGURE 2


N
dirt road
95'
sewer pipe probes
4'9"
thermometer mounted on stick
24" above ground surface
8'10"
3'5"
soil probes in hole
~50'
scale
0'
10ft
MacARTHUR FIELD SITE

ANACONDA DUMP SITE - SOIL PROBES IN SPIKE

AUGUST 8,9-1977

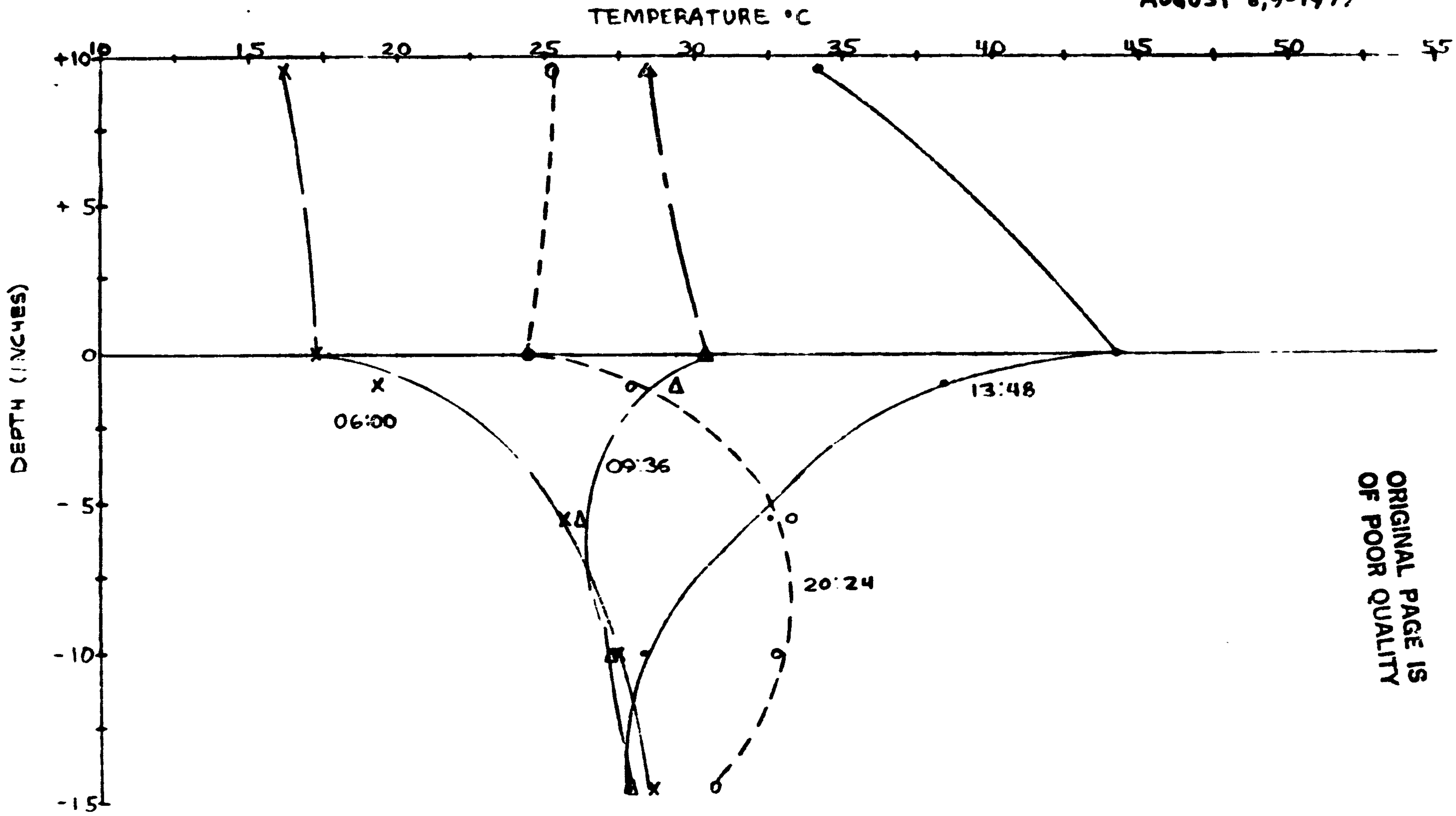


FIGURE 4

ANACONDA DUMP SITE - AIR PROBES IN SEWER PIPE AUGUST 8-9, 1977

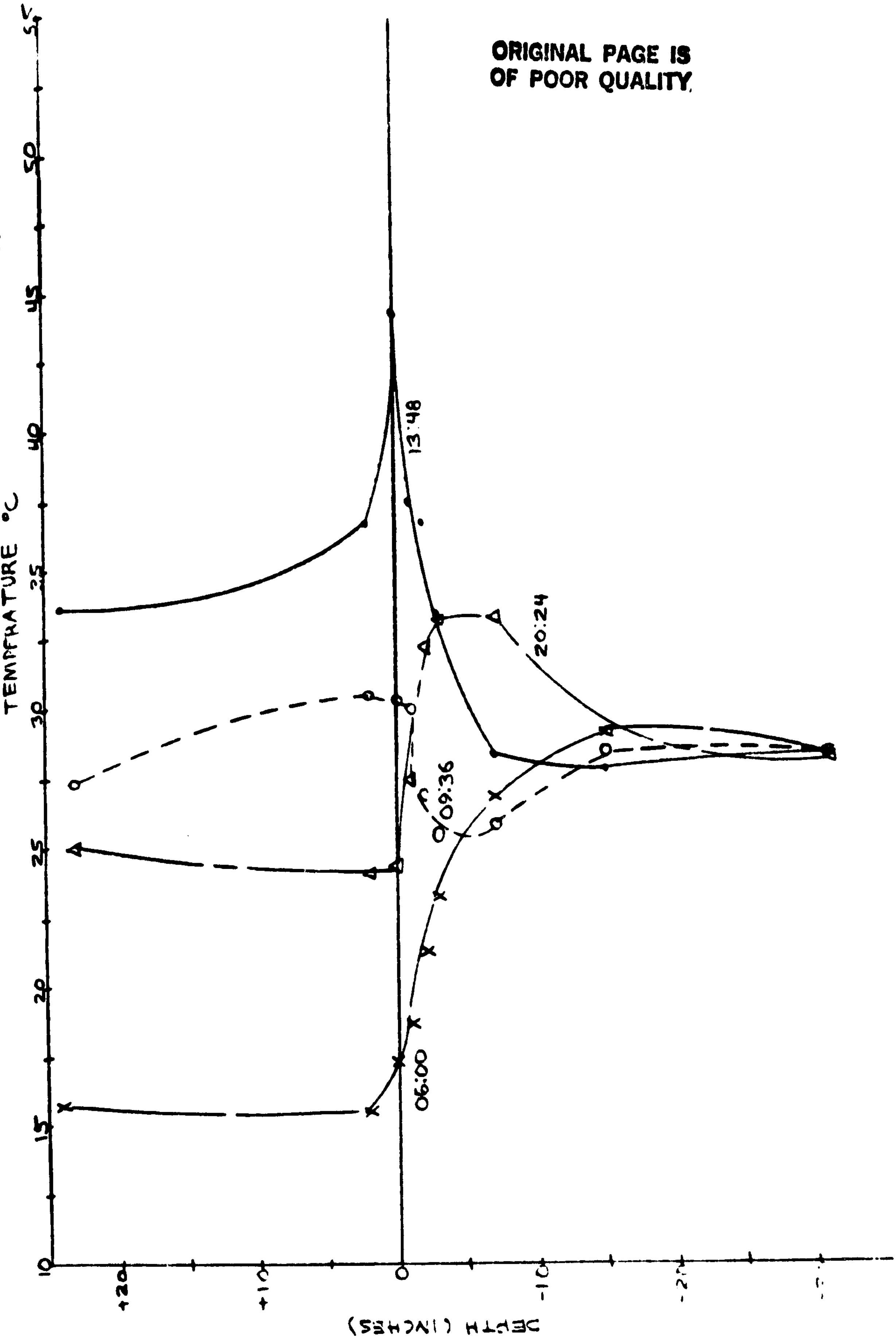


FIGURE 5

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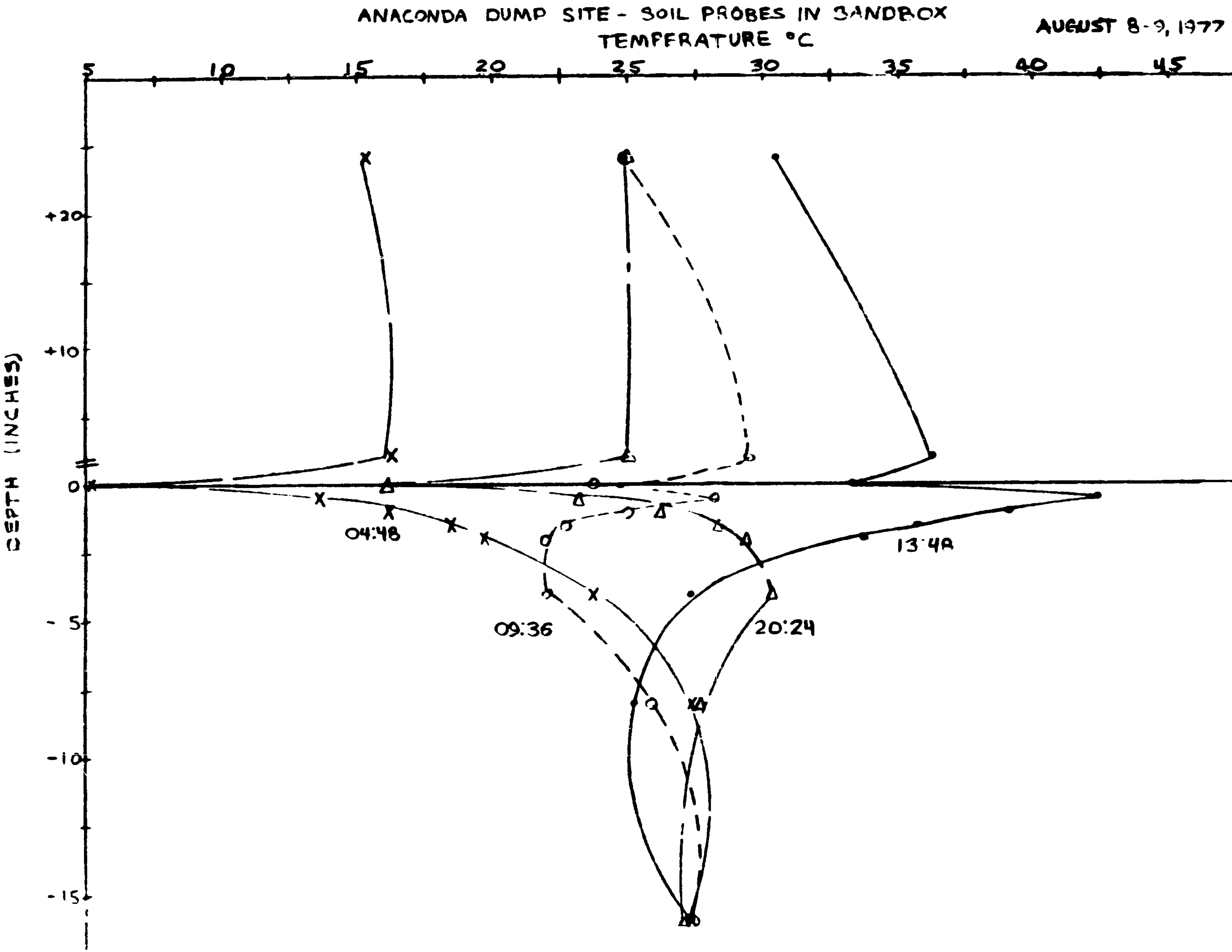


FIGURE 3

MACARTHUR SITE-SOIL PROBES IN HOLE

AUGUST 8-9, 1977

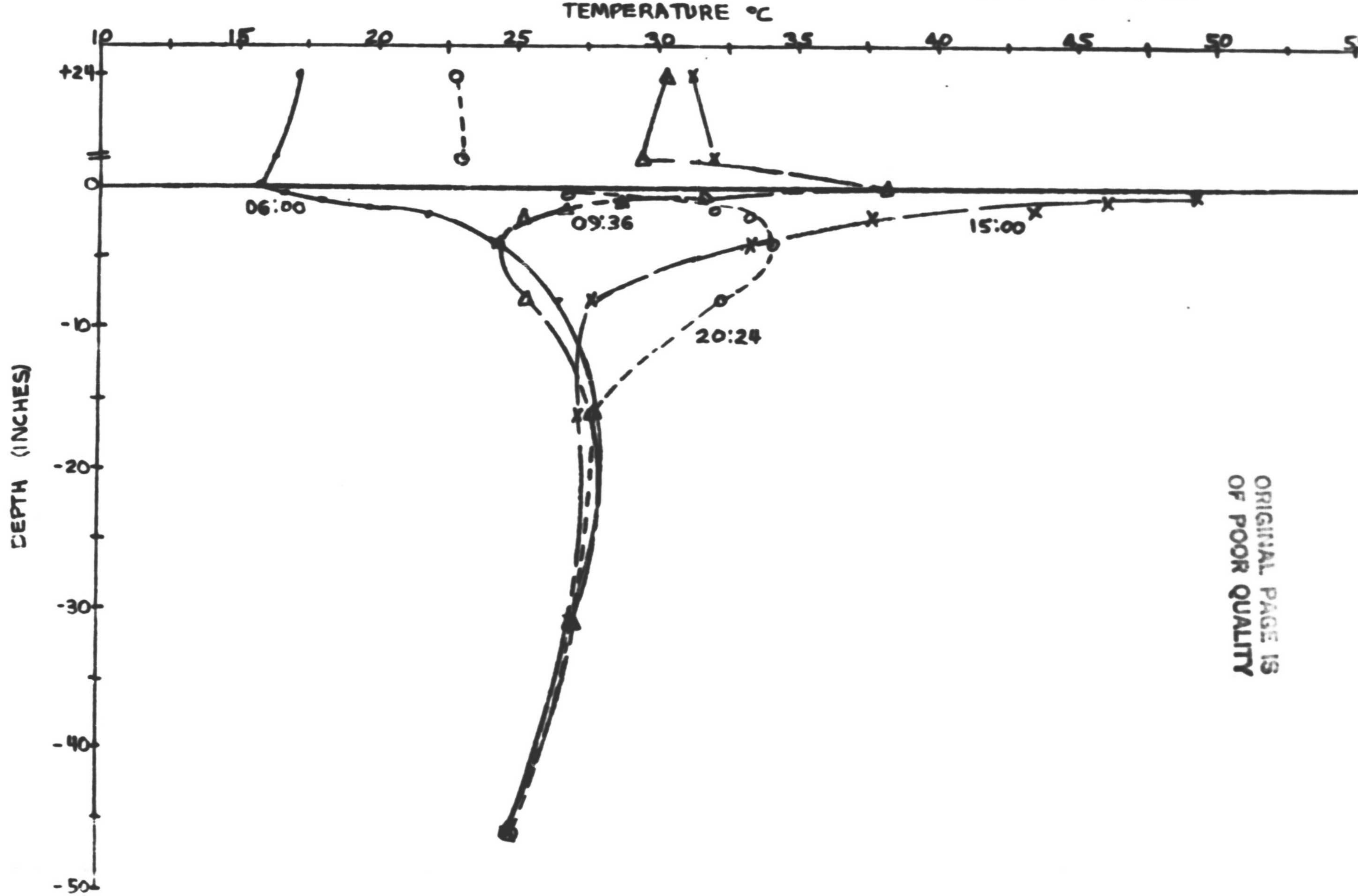


FIGURE 7

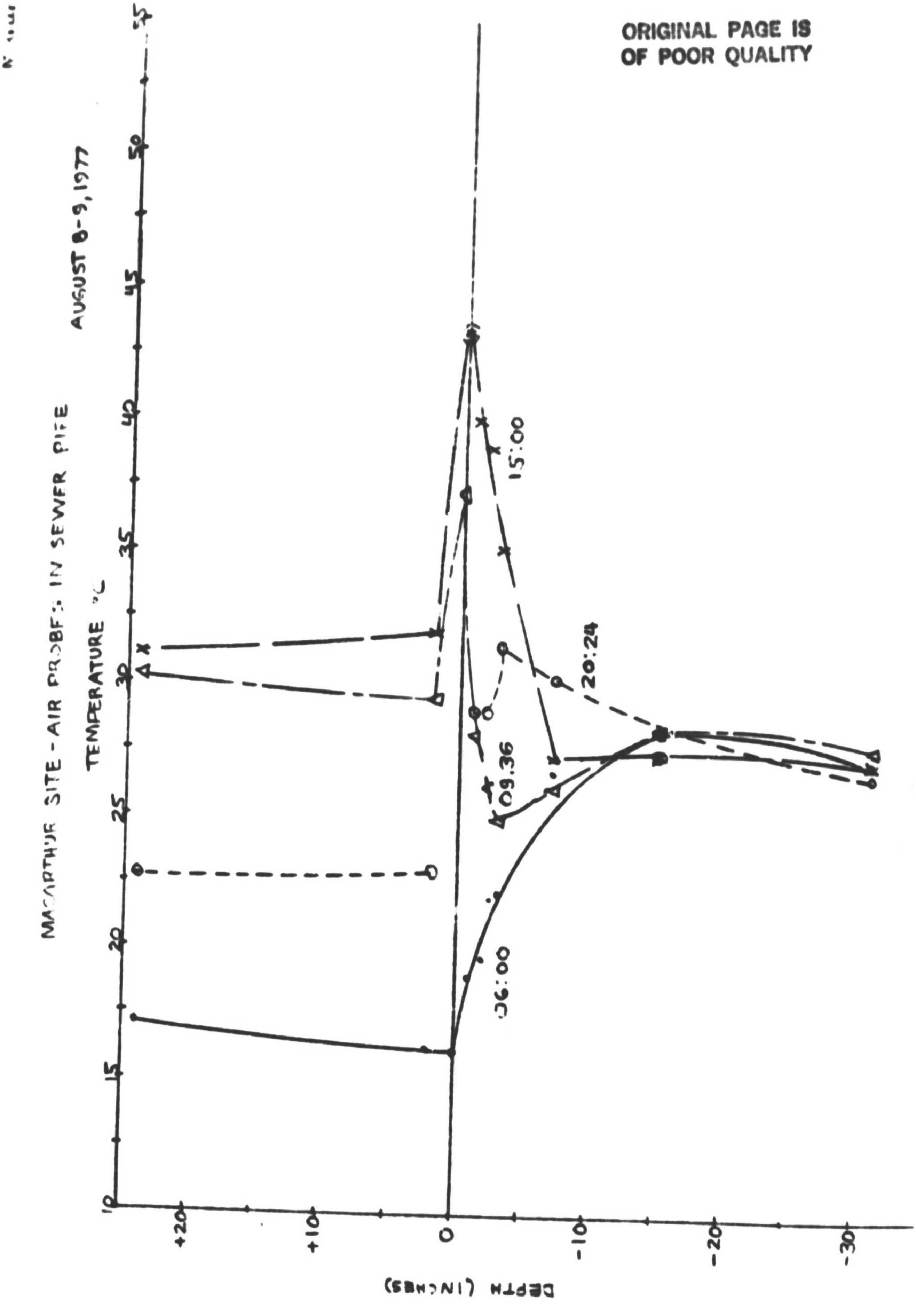

MACARTHUR SITE - AIR PROBES IN SEWER PIPE
AUGUST 8-9, 1977
TEMPERATURE °C
10
15
20
25
30
35
40
45
50
55
15:00
20:24
09:36
06:00
+20
+10
0
-10
-20
-30
DEPTH (INCHES)

FIGURE 6

2. Sol-a-Meter Readings

A sol-a-meter at both stations was used to sense the short-wavelength radiant flux incident to the ground surface. Both units were placed away from the other instruments on a sheet of grey plasterboard and connected to an amplifier and voltmeter to enable easy readout. At the Anaconda Dump site, the sol-a-meter was located on flat ground representative of the study area. At the MacArthur site, a similar set-up was placed on a nearby knoll.

The graphed results (Figures 8 and 9) show that the radiant flux incident at MacArthur was slightly greater, particularly in the late morning. This effect could be the result of: calibration problems; a difference in the illumination or atmospheric conditions caused by haze or clouds; proximity to reflecting surfaces; or problems in leveling the units.

Between sunset and sunrise (circled on both graphs) the measurements are nearly constant, maximum incident radiance occurred close to 1300 hours at both sites.

Figures 8 and 9 show the plot of sol-a-meter readings against time. The sol-a-meter measures the radiant flux incident to the ground surface. The original data (Appendix 1)was calibrated to cal $cm^{-2}min^{-1}$ employing the conversion charts in Appendix 2. The curve for the uncalibrated values is designated by dots, the calibrated curve by the "x" symbol. The circled points in both figures denote the local sunset and sunrise. In Figure 8, no data was recorded between 2100 and 0600 hours.

3. Net Radiometer

The net radiometer reading represents the difference between the short and long wavelength radiation hitting a target and that reflected back off the target. Results from the Anaconda dump site are given in Figure 10. The

SOL-A-METER READINGS AT ANACONDA DUMP SITE
AUGUST 8-9, 1977 (65407, AMP 3)

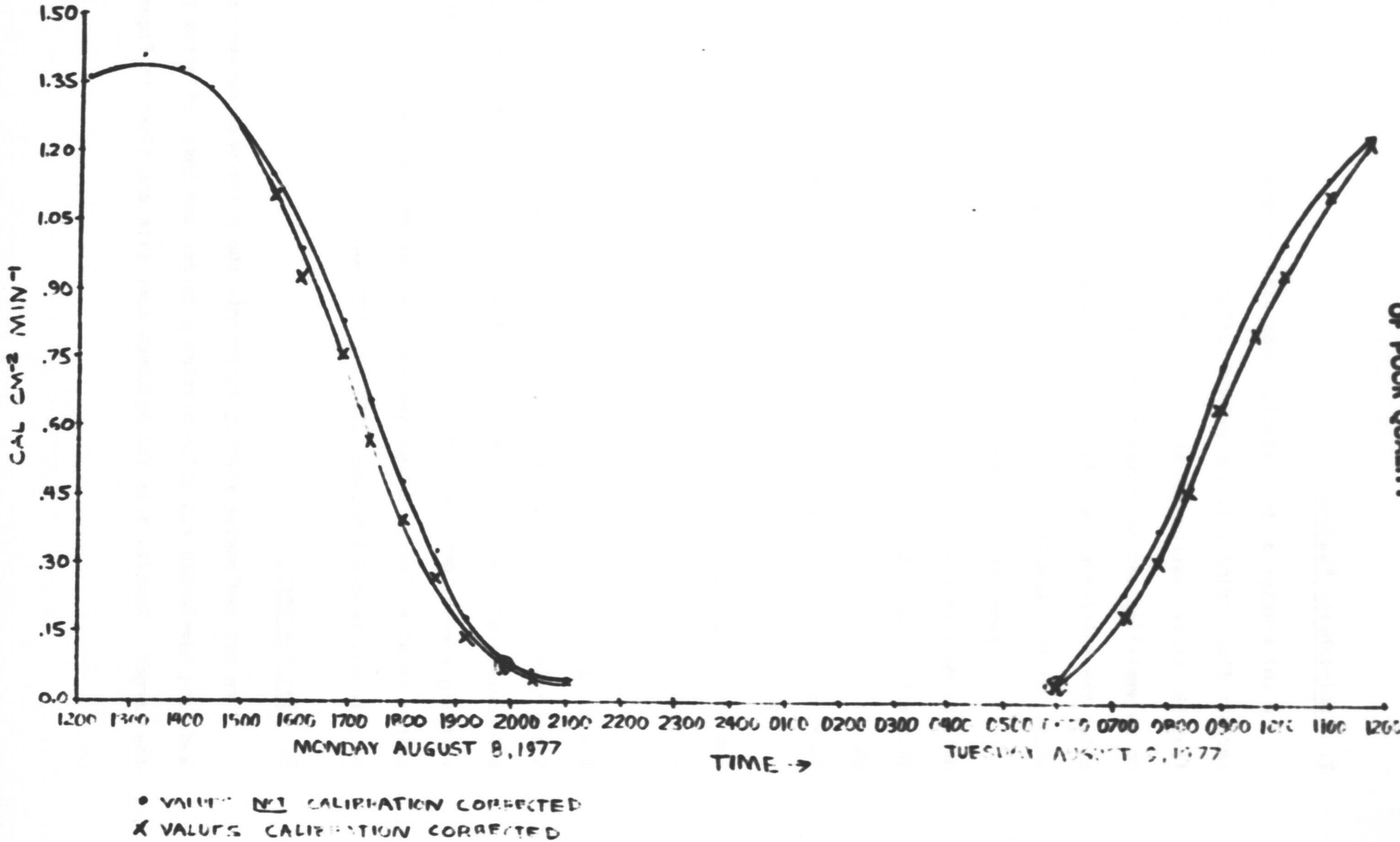


FIGURE 8

SOL-A-METER READINGS AT MACARTHUR SITE
AUGUST 8-9, 1977 (2102, AMP 2)

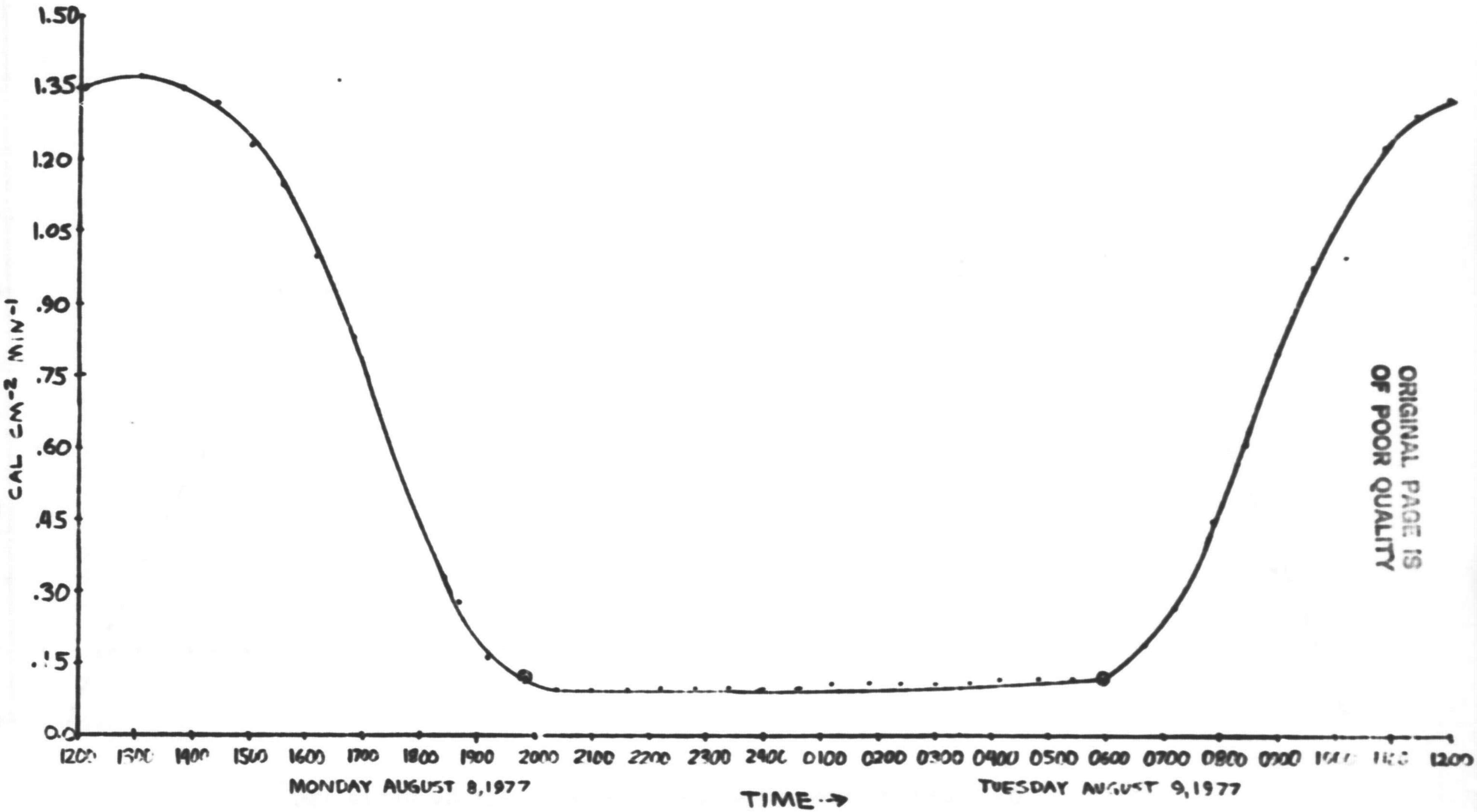


FIGURE 5

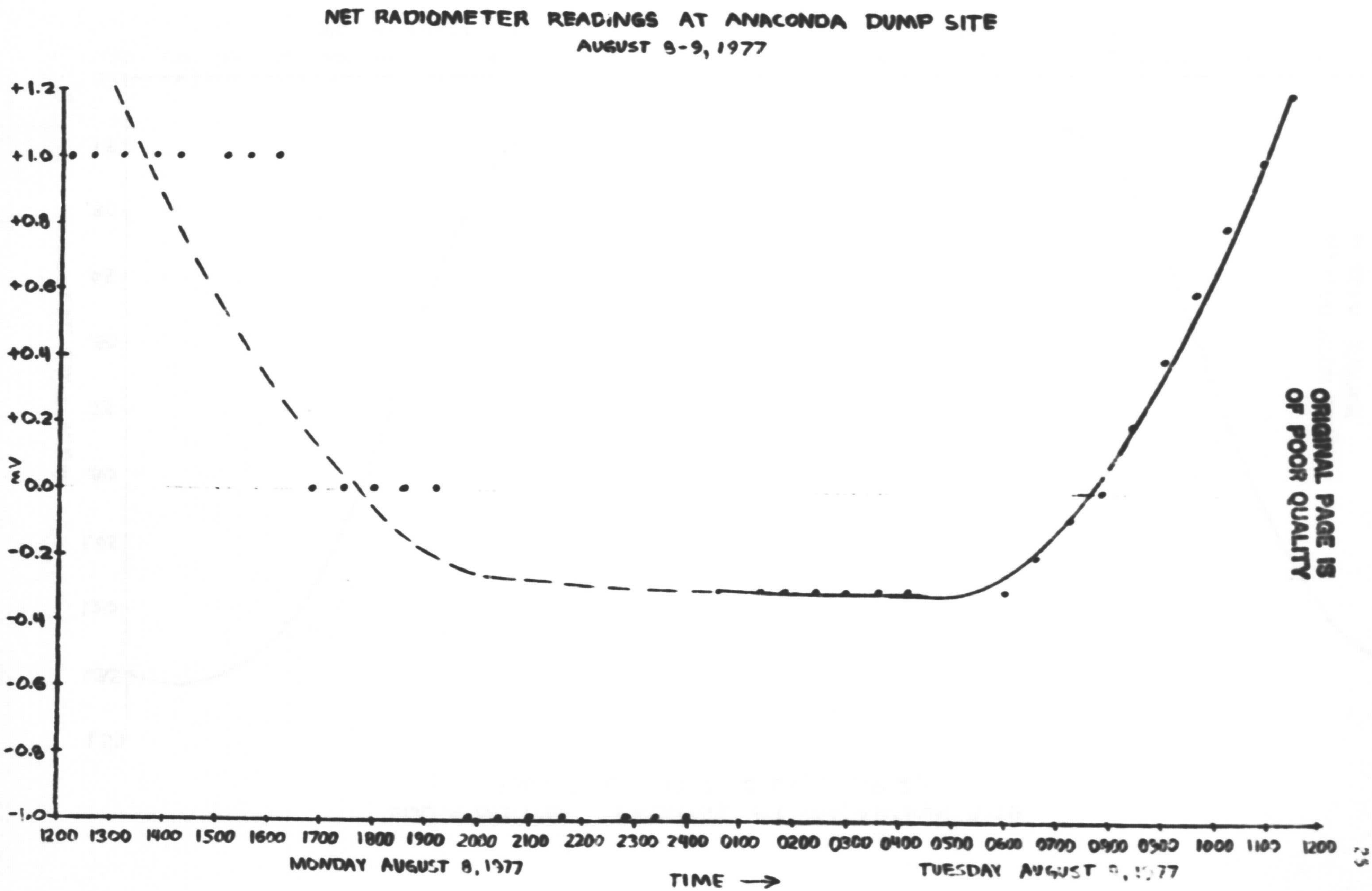

NET RADIOMETER READINGS AT ANACONDA DUMP SITE
AUGUST 8-9, 1977
+1.2
+1.0
+0.8
+0.6
+0.4
+0.2
mV 0.0
-0.2
-0.4
-0.6
-0.8
-1.0
1200 1300 1400 1500 1600 1700 1800 1900 2000 2100 2200 2300 2400 0100 0200 0300 0400 0500 0600 0700 0800 0900 1000 1100 1200
MONDAY AUGUST 8, 1977
TIME →
TUESDAY AUGUST

FIGURE 10

original data can be found in Appendix 1.

Interpretation of the data was complicated by the rounding off of data values taken Monday August 8. The dotted line through data recorded August 8 is an approximation as to how the curve may have appeared if rounding did not occur. These curves appear similar to the Anaconda dump site sol-a-meter readings, however, conclusive comparisons are difficult to suggest.

4. Exotech Landsat Band Radiometers.

The Exotech units were employed to measure the reflectance properties of the test sites. Two units were employed. One unit viewing the target with a 1 degree field of view records radiant exitance ; the second unit, looking vertically skyward with a 2 pi field of view, records total global irradiance. The division of the radiant exitance value by global irradiance yield the apertured reflectance* of the target in the four Landsat wavelength intervals.

Table 2 lists the albedo value for each site, calculated by averaging the four Landsat reflectance values over the wavelength region 0.5 — 1.1 micrometers.

TABLE 2

Test Site Albedo

Site	Albedo (%)
Anaconda Dump Site	22.0
MacArthur Site	27.0
Ottawa Sand	54.0

* Some prefer"hemispherical conical reflectance".

5. Recording Thermometers

Results from the two recording thermometers at the leach pond are given in Figures 11 and 12. The original data and calibration information are located in Appendix 3. Problems were encountered calibrating the two thermometers (Appendix 3).

Figure 11 gives the thermometer readings every 30 minutes during the 24 hour data collection period at station A located near the water outlet. Figure 12 is a similar graph of station B in a calmer part of the leach pond.

By comparing these two figures, it is apparent that station A remained warmer than station B throughout the 24 hour period. Temperatures at station B varied 8.4 °C, from 21.5 to 29.9 °C, while the variation at station A was 7 °C, from 24.0 to 31.0 °C. The smaller variation at A was anticipated. The greater flow of water at A caused greater mixing which would tend to keep the water temperature more uniform. However, we anticipated station B to have had the highest and lowest recorded temperature, not just the lowest as seen by the data.

6. Soil Samples

Soil samples were collected at both stations at depths corresponding to those of the temperature probes. Moisture content by percent weight was determined for each sample, (Appendix 4).

Figure 13 shows the moisture contents for the soil surrounding the spike and for the soil surrounding the sewer pipe at the Anaconda dump station. The points on the curve represent the values determined.

The moisture content profiles for soils at the MacArthur site are given in Figure 14. The dotted line in the sewer pipe curve is based on samples whose size was determined to be inadequate to give meaningful results. The

RECORDING THERMOMETER READINGS AT ANACONDA LEACH POND
STATION "A" NEAR WATER OUTLET
8/7 - 8/9/77

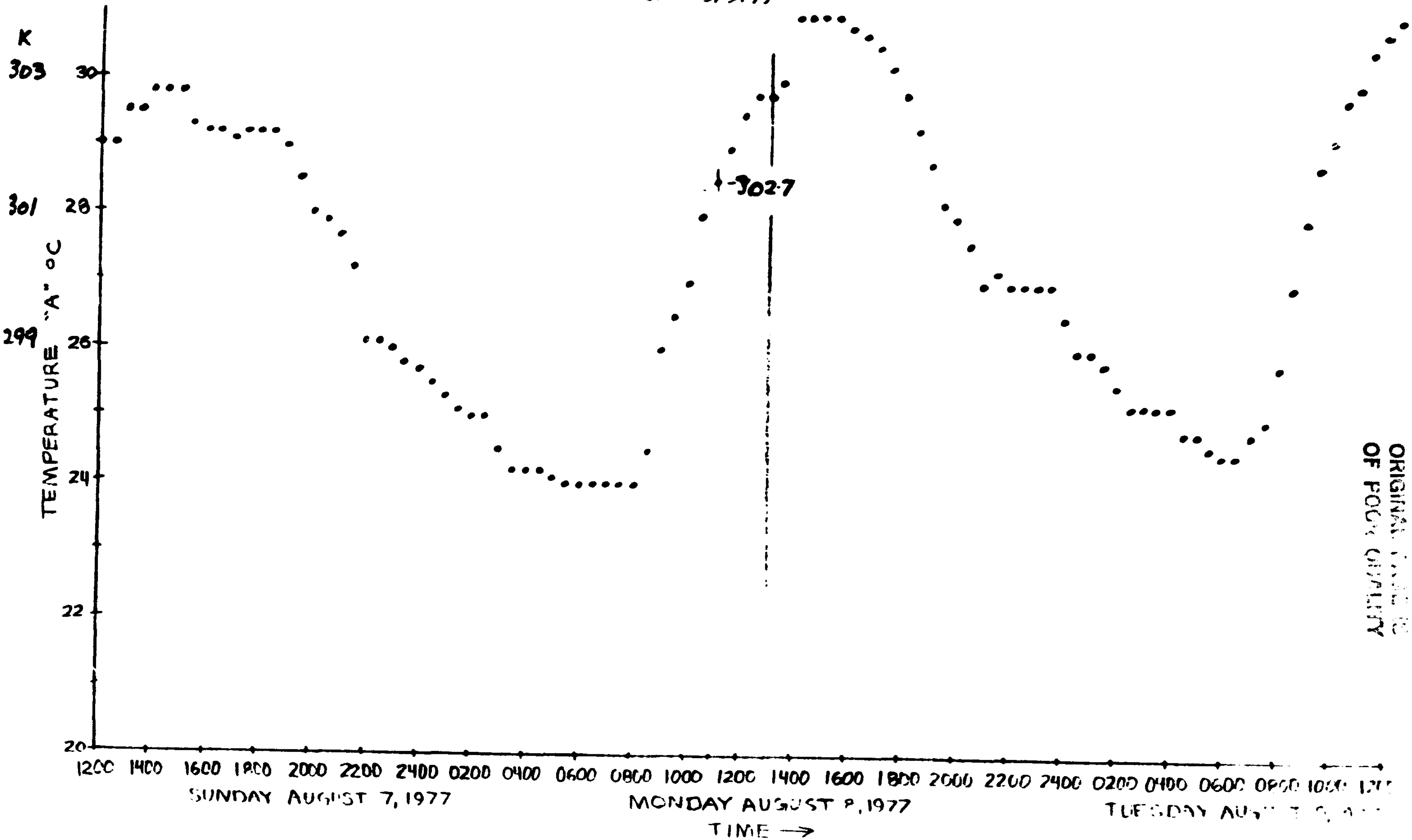


FIGURE 11

RECORDING THERMOMETER READINGS AT ANACONDA LEACH POND
STATION "B" AWAY FROM WATER OUTLET
8/7 - 8/9/77

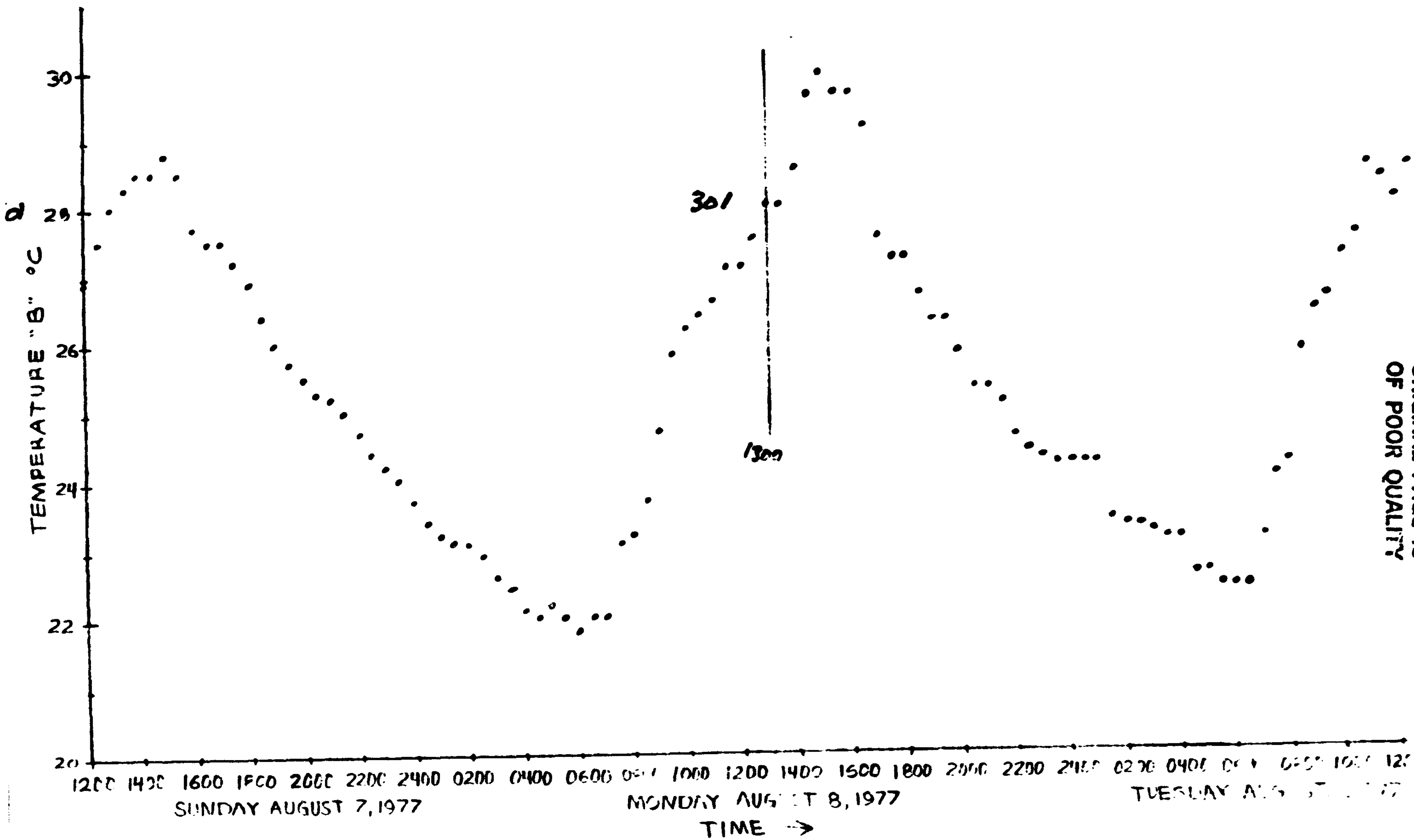


FIGURE 12

MOISTURE CONTENT OF ANACONDA DUMP SITE SOILS
AS RELATED TO DEPTH 8/5/77

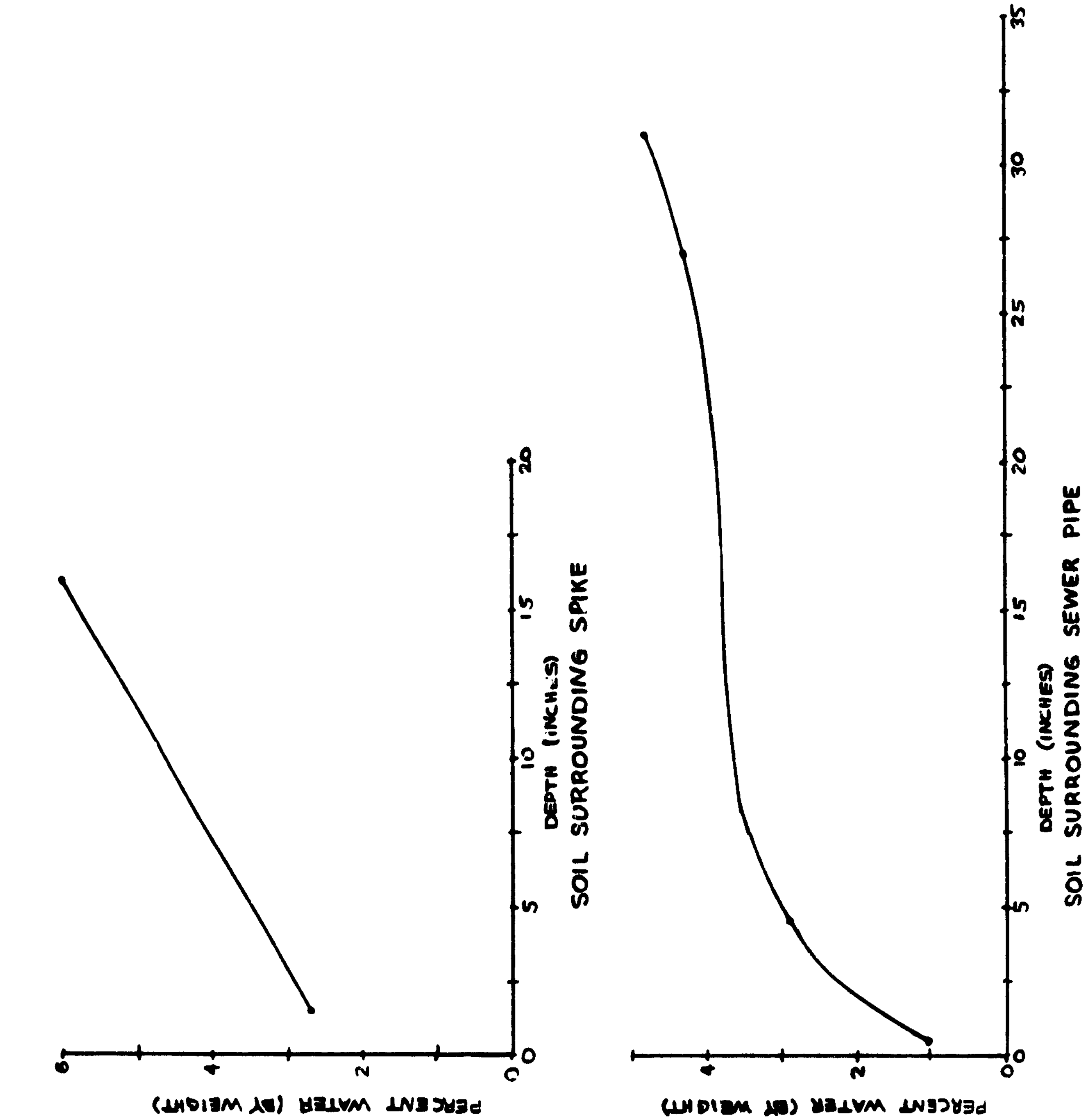
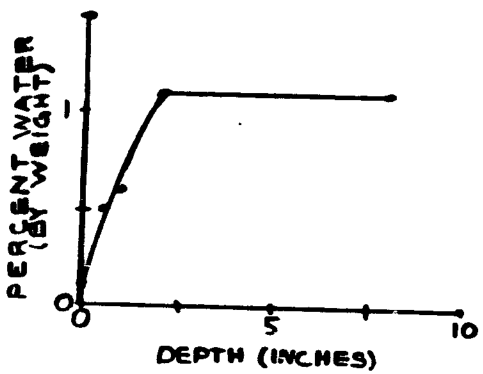


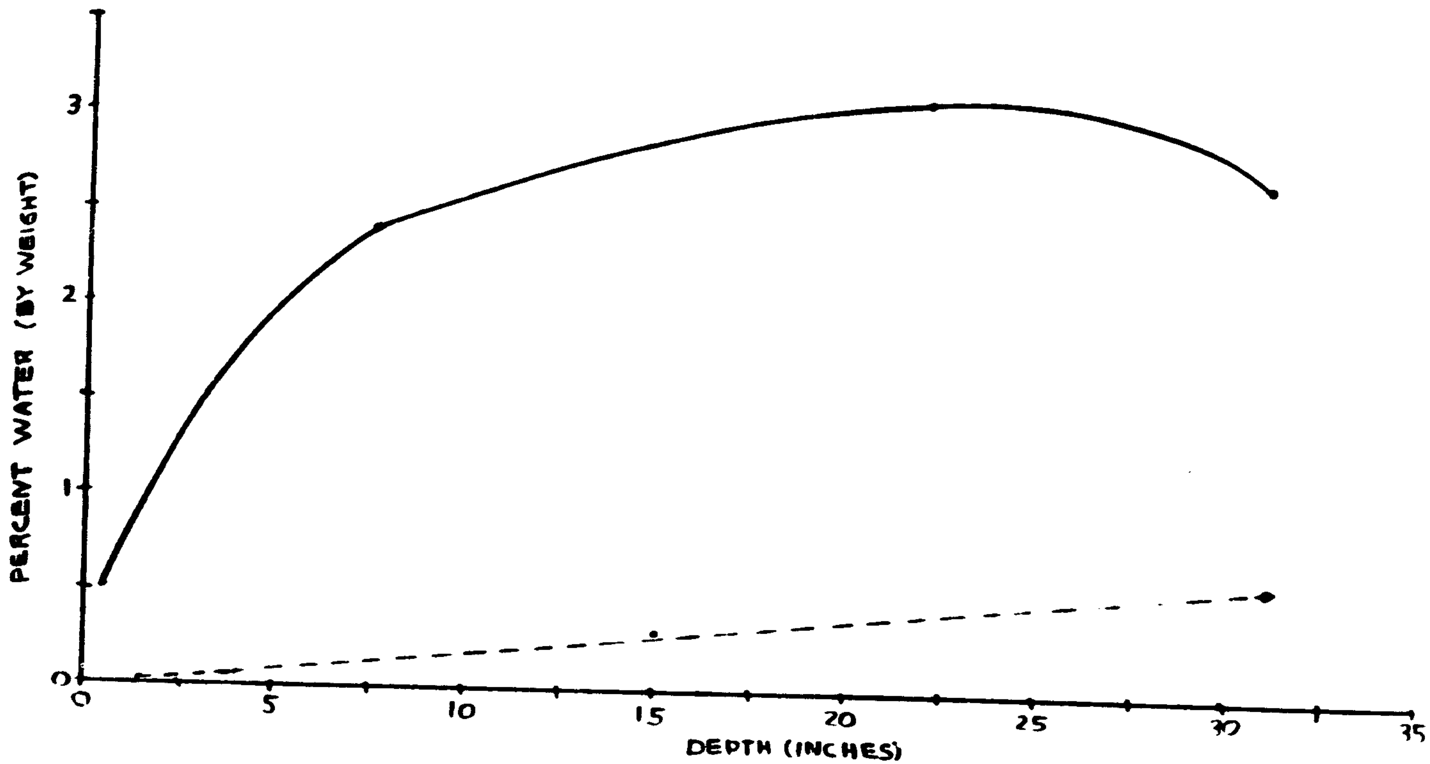
FIGURE 13

M. KELLER

MOISTURE CONTENT OF MACARTHUR SITE SOILS
RELATED TO DEPTH 8/5/77, 8/9/77



SOIL SURROUNDING SOIL PROBES



SOIL SURROUNDING SEWER PIPE

--- SAMPLES TAKEN FROM SEWER PIPE IN VERY SMALL AMOUNTS; LESS ACCURATE.

solid lines are the best estimates of the soil moisture profiles based upon the significant data.

III. THERMAL PARAMETER DETERMINATIONS AND MODELLING (AUGUST MISSION)

The detailed field measurement program carried out in August 1977 at Yerington Nevada was designed to supply the surface meteorological and thermal data necessary to accurately model the diurnal surface temperature. The contemporary principles of one-dimensional heat flow (Carslaw and Jaeger, 1959) on the Earth's surface have been converted by a number of scientists into mathematical models to resolve surface temperature. The use and understanding of the modelling results are an extremely valuable tool in infrared studies.

To better understand and analyze the significance of thermal modelling, the components of three previously developed models which compute the diurnal surface temperature were studied. By comparing the results of these models using the field data acquired at Yerington, the significance of various thermal parameters and the applicability of their results should be better understood.

The three models compared in this study were:

1) SURTEMP, a Laplace transform model of the one-dimensional heat conduction equation developed at the Stanford Remote Sensing Lab (Lyon, 1974).
2) WATEMP, a linearized version of the original Laplace transform model developed by Watson (1971 and 1974).
3) CSIROTEMP, a least squares estimation of parameters of surface temperature developed by A. Green, (personal communication, 1976).

Additional models have been developed by Outcalt (1972), Rosema (1974), and Kahle (1976), however, they were not available for this study. Previous comparisons of the SURTEMP and WATEMP models (Marsh, 1975) showed that with identical input parameters the model surface temperature results are within 1 - 4°C. No comparison of the SURTEMP and CSIROTEMP models have been previously undertaken.

Input parameters for the SURTEMP and WATEMP models can be directly extracted or indirectly calculated from the field data.

A. THERMAL MODEL PARAMETERS

1) Albedo — the short-wavelength (0.5 - 1.1 μm) reflectance of the surface as measured by the Exotech radiometers (see Table 2, Section II).

2) Solar Declination — used to calculate solar insolation and determined for any particular day from the solar ephemeris, 15.0° for August 8-9, 1977.

3) Latitude — the site latitude, necessary to calculate solar insolation, 38.9° for the Yerington test sites.

4) Strike and Dip — the orientation of the surface as it is affected by the solar input. The three Yerington sites were essentially level.

5) Emissivity — the emissivity of the site determines the radiation temperature observed, most natural surface materials have emissivities in the 8 - 14 μm region between 0.89 and 0.99. For the modelling work in this study the emissivities are approximated at 0.90.

6) Sky Temperature — the sky back radiation hitting the surface. Van Wijk and Shulte (1963) give an empirical formula based upon surface air temperature and vapor pressure for the estimation of sky temperature:

$$T_{sky} = T_a f(P_w)^{0.25}$$

where

T_a = air temperature

P_w = water vapor pressure, and for clear sky conditions

$f(P_w) = a_h + b_h P_w^{0.25}$, $a_h = 0.678$ and $b_h = 0.041$.

Based upon the mean air temperature and vapor pressure as measured at the Yerington Dump site the sky temperature was calculated to be 276.5°K. Measurements made with the net radiometer (Section II-B-3), of net radiation (R^{net}) and with the sol-a-meter of short-wavelength radiation ($R^{\downarrow}_{short}$), along with the surface albedo (a), were employed to determine the sky temperature (R^{sky}_{long}) from the relationship:

$$R^{net} = (1-a)\, R^{\downarrow}_{short} + (R^{solar}_{long} + R^{sky}_{long}) - R^{\uparrow}_{long} .$$

Results from these calculations yield a sky temperature of 272°K. Based upon the sensitivity of the SURTEMP and WATEMP models, an inaccuracy of ± 4 - 5°K in the value of sky temperature would produce a change in the calculated diurnal temperature of 0.5 - 1.0°C. This preliminarily indicates that if a net radiometer is unavailable, the Van Wijk and Shulte (1963) empirical relationship should yield reasonably accurate results.

7) Cloud Cover - Wind Factor — a fractional multiplicative factor to compensate for a decrease in solar insolation at the surface due to clouds or wind. This factor was estimated to be 0.2 for conditions at the Yerington test sites on August 8-9, 1977.

B. TEST SITE MODEL RESULTS

To assess the accuracy of thermal inertia modelling results the Stanford Remote Sensing Lab has employed (Lyon and Marsh, 1976), a standard material with known thermal properties in its thermal infrared studies. The standard material is 20/30 mesh Ottawa (0.5 - 0.8 mm quartz) sand, for which both thermal conductivity and heat capacity had been determined by direct laboratory techniques at varying moisture contents (Moench, 1969).

The sand was placed in a well insulated (plate 1) Douglas fir wood box at the Anaconda Dump site. The moisture content of the sand was approximated at 0.02 cm^3/cm^3 which would give a thermal inertia of 0.03 cal $cm^{-2} \cdot C^{-1} sec^{-\frac{1}{2}}$. The SURTEMP and WATEMP models were then run to determine the accuracy of the input parameters. By comparing the observed surface temperatures of the sand, (recorded by the PRT-5) with the model predicted temperatures, for 20 equally spaced time increments in a 24 hour period, the error limits of the input parameters and models can be analyzed. Table 3 gives the input parameters for the Ottawa sand, and Table 4, the standard error of the fit (SE) of the diurnal surface temperature for a range of thermal inertia values. The standard error of the fit is calculated from the formula:

$$SE = \sqrt{1/n-1\ \Sigma(T_m - T_c)^2}$$

where n = the number of sample points (20) during a 24 hour period

T_m = measured surface temperature of the Ottawa sand

T_c = model calculated surface temperature of the Ottawa sand.

MODEL PARAMETER VALUES FOR YERINGTON SITES, AUGUST 8,9 1977

	Anaconda Dump Site Crushed, leached quartz monzonite		McArthur Site Granodiorite soils	
Albedo	22.0		27.0	
Emissivity	0.90		0.90	
Cloud Cover	0.2		0.2	
Latitude	38.9		38.9	
Declination	15.0		15.0	
Dip	0.0		0.0	
Strike	0.0		0.0	
Sky "Temperature"	272K		272K	
Moisture Content	Spike	Sewer pipe	Spike	Sewer pipe
-1"	2.7%	1.0	1.0	1.3
-10"	4.5	3.4	1.0	2.5
-16"	6.0	3.5	--	3.0

TABLE 3

Input Parameters for the Ottawa Sand Study

Albedo : 0.54	Solar Declination : 15.0
Emissivity : 0.90	Latitude : 38.9
Cloud Cover : 0.20	T_{sky} : 272°K
Dip : 0.0	Strike : 0.0

TABLE 4

Thermal Model Accuracy

T.I.	Moisture Content	Standard Error of Fit	
(cal $cm^{-2}C^{-1}sec^{-\frac{1}{2}}$)	(cm^3/cm^3)	SURTEMP	WATEMP
0.017	0.0	6.66	11.15
0.030	0.02	5.45	9.24
0.037	0.04	5.65	9.25
0.043	0.09	5.96	9.49

Both models produce the minimum error between observed and model predicted surface temperature with a thermal inertia of 0.03 cal cm^{-2} $°C^{-1}sec^{-\frac{1}{2}}$. The SURTEMP model best fit produces an error of about 5.5°C, the WATEMP model 9.24°C. These results indicate that both models appear to correctly approximate the thermal inertia of the Ottawa sand under the meteorological conditions present August 8-9, 1977. However, their ability to reproduce the surface temperature is at best within 5 - 10°C.

The CSIROTEMP model requires input of the site latitude, albedo, solar declination, and observed temperature through the diurnal cycle. Estimates of the mean surface temperature, thermal inertia, and back radiation are also input. The model then re-estimates these terms to arrive at a least squares estimate of these values based upon the observed surface temperatures. In an alternate mode the mean surface temperature and back radiation are re-estimated keeping the thermal inertia at the original input value. Model results are given in Table 5 for the expected range of thermal inertia values kept constant.

TABLE 5

CSIROTEMP Model Results

T.I. ($cal\ cm^{-2}\ °C^{-1} sec^{-\frac{1}{2}}$)	Standard Error of Fit CSIROTEMP
0.020	3.1
0.030	1.8
0.040	1.3

CSIROTEMP model results allowing the thermal inertia to be re-estimated to arrive at a best fit calculated the thermal inertia of the Ottawa sand to be 0.037 cal cm^{-2} $°C^{-1}$ $sec^{-\frac{1}{2}}$. This is off by 0.007 from the SURTEMP and WATEMP results, however, it is important to note the extremely small difference in the standard error between a thermal inertia of 0.030 and 0.037 in all three models. It appears reasonable to conclude from these results that

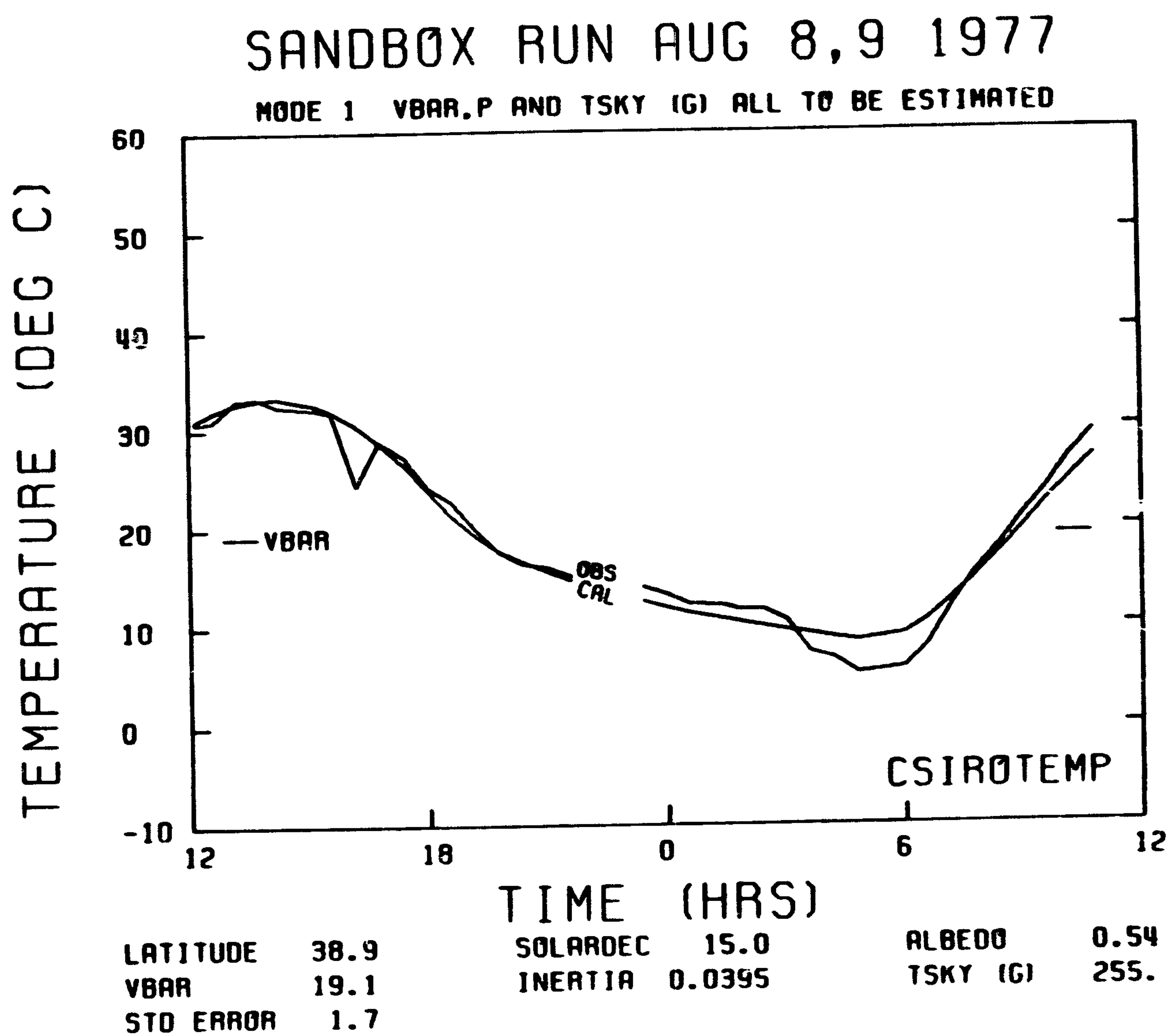


FIGURE 15a Yerington Dump Site ,Sandbox Experiment, MODE 1 --all estimated.

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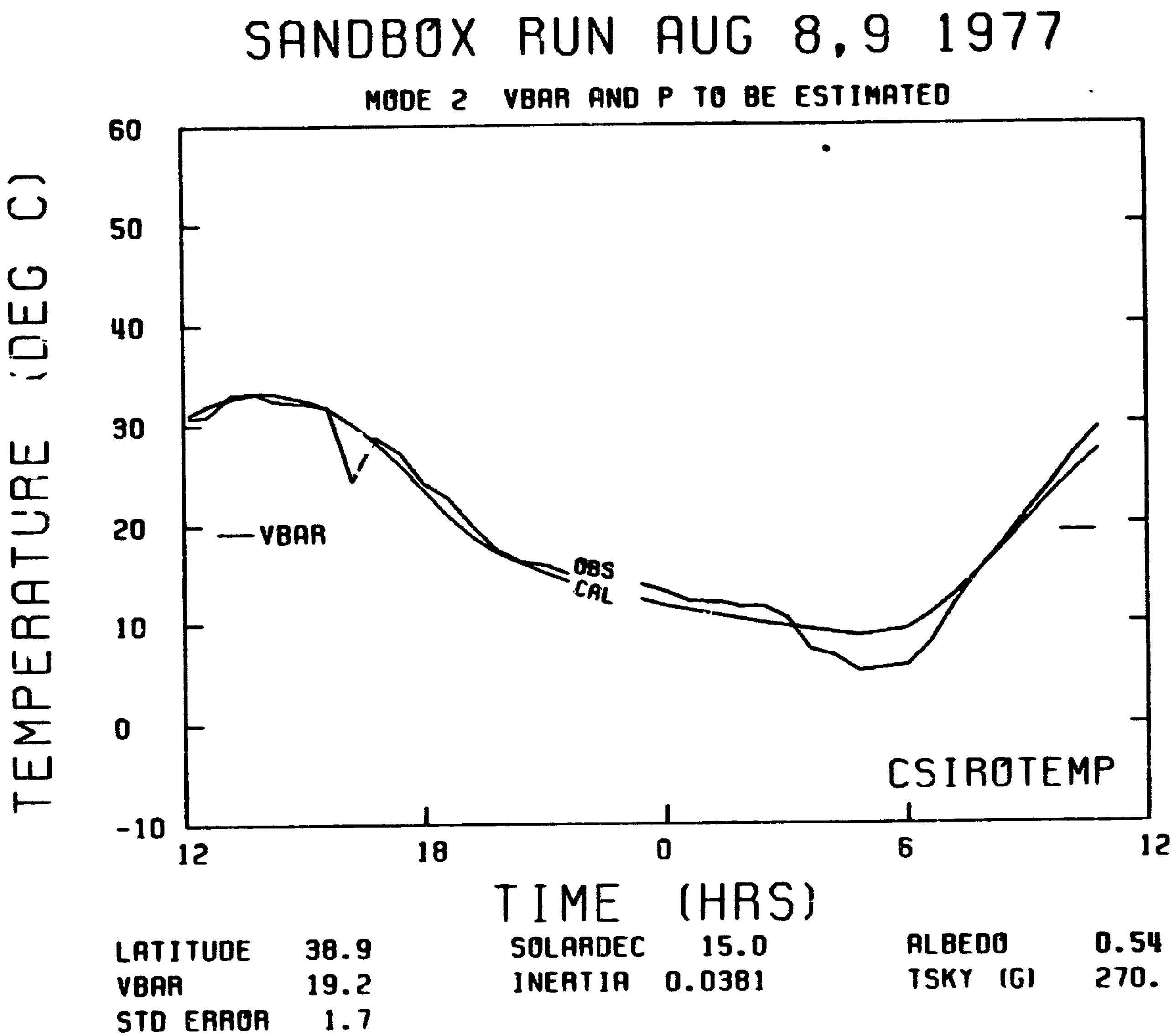

FIGURE 15b Yerington Dump Site, Sandbox Experiment--CSIROTEMP Ave. temp and Thermal Inertia estimated.

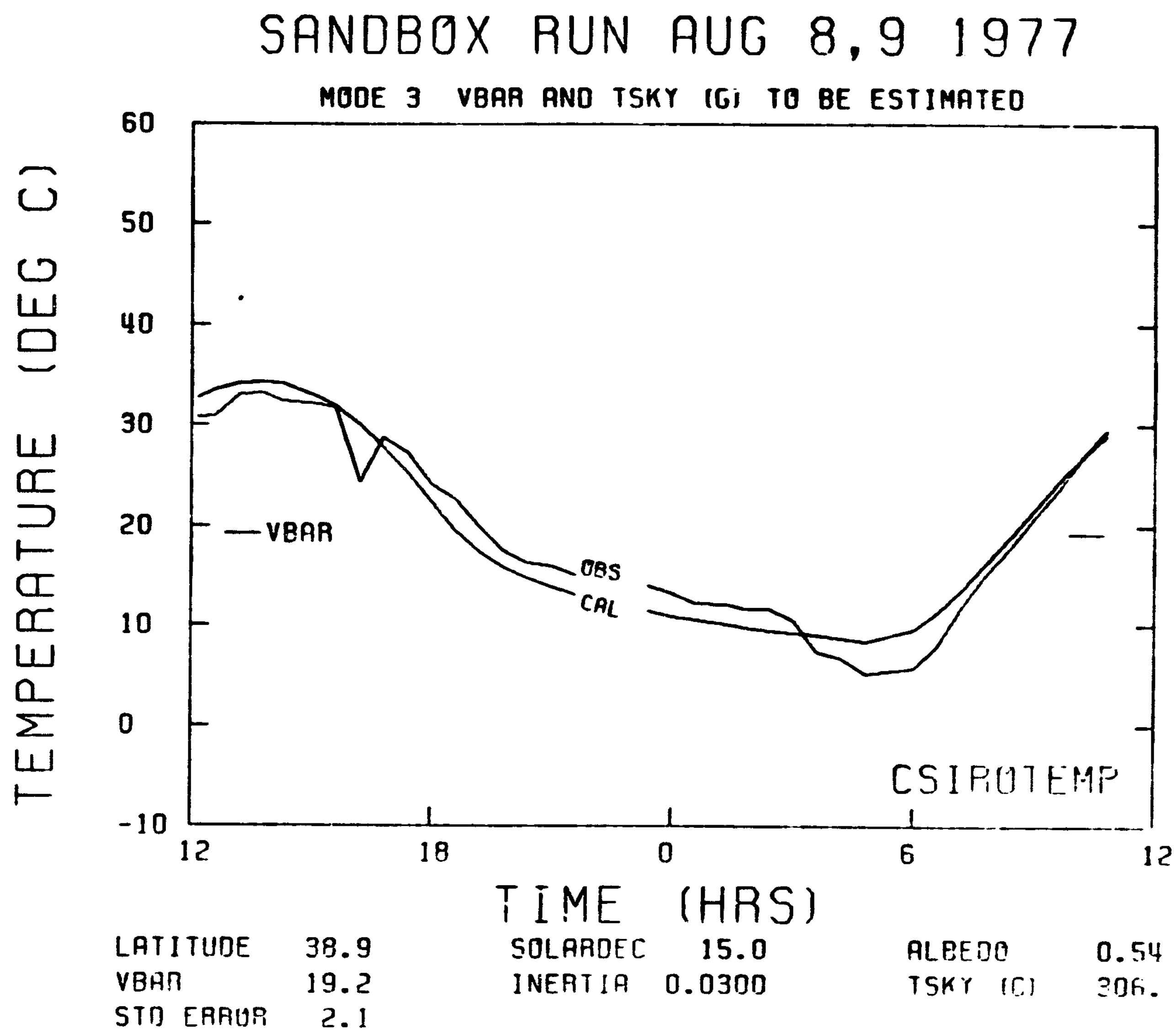

FIGURE 15c Yerington Dump Area, Sandbox Experiment--CSIRO Ave. Temp and Atmospheric parameter (G) to be estimated.

all three models were able to calculate the thermal inertia of the Ottawa sand within approximately 20% based upon the input parameters and their associated error limits.

The next step in the analysis employed the SURTEMP model to estimate the thermal inertia of the Anaconda Dump and MacArthur test sites. The input parameters used in the Ottawa sand run were kept constant, changing only the albedo of the site as determined from the Exotech measurements. The standard error of the fit between the observed and model calculated diurnal temperatures for the anticipated range of thermal inertia values were then calculated (Table 6).

TABLE 6

Yerington Test Site SURTEMP Model Results

T.I.	Standard Error of Fit	
(cal cm^{-2} $°C^{-1}$ $sec^{-\frac{1}{2}}$)	Anaconda Dump	MacArthur
0.020	----	6.57
0.030	12.36	5.76*
0.035	11.92	6.24
0.040	11.69	6.87
0.045	11.58*	7.42
0.050	11.59	----
0.060	11.62	----

* = best fit

These results indicate the thermal inertia of the test sites can be estimated within 10 to 15 percent at 0.030 for the MacArthur site and 0.045 for the Anaconda Dump site. The error at the Anaconda Dump site in the fit of observed to calculated diurnal temperature is nearly double that of the MacArthur and Ottawa sand sites. This fact is difficult to explain unless the albedo or local meteorology was more variable than evidenced in the measurements.

C. APPROXIMATION TO A RADIANT HEATING METHOD FOR DETERMINING THERMAL INERTIA

Schultz (1968) developed a novel method for nondestructively determining the thermal inertia of solids near ambient temperature. The method involved heating, with radiant energy, a small area on the surface of a "semi-infinite" solid for a short period of time. The characteristically shaped temperature rise recorded with an IR radiometer is compared with that of a reference standard yielding the thermal inertia of the sample from the relationship:

$$\text{T.I.}_{\text{sample}} = \frac{\Delta T_{\text{standard}}}{\Delta T_{\text{sample}}} \times \text{T.I.}_{\text{standard}} \times \left(\frac{\varepsilon_{\text{sample}}}{\varepsilon_{\text{standard}}}\right)^2$$

As a means of approximating Schultz's method the Ottawa sand was employed as the reference standard and the natural solar heating was employed, over a defined period of time, as the source of radiant energy. An early morning time period (0710-0825) was chosen to run the experiment due to the more stable meteorological conditions and faster heating in this time frame. Results from the calculations yield a thermal inertia of the MacArthur site of 0.029 cal cm^{-2} C^{-1} $sec^{-\frac{1}{2}}$ and a value of 0.031 cal cm^{-2} C^{-1} $sec^{-\frac{1}{2}}$ for the Anaconda dump site.

The MacArthur thermal inertia result is quite close to the value determined by the modelling, however, the Anaconda Dump site is off by nearly 35%. From these results it is impossible to claim success for this approximation to Schultz's method. The numerious influencing meteorological variables which existed during our heating history obviously detracted from the usefulness of our technique. Under Schultz's ideal conditions there are no unknown variables and the heating rate is kept constant. The development of this method into a field instrument with its own heat source might be a very useful next step in thermal inertia studies.

IV. SECONDARY FIELD STUDY — YERINGTON NEVADA (DECEMBER 8-9, 1978)

A second field mission was carried out coincident with the December 8th and 9th (1978) HCMM satellite overpass of the Yerington area. Due to weather conditions and availability of personnel, it was impossible to complete as detailed a measurement program as accomplished during the August 1977 mission. Data recorded during this mission included ground surface temperatures (PRT-5), subsurface soil temperatures at ½, 2, and 8 inches (thermistor probes), air temperature, windspeed, and cloud cover conditions.

The sites chosen for this study were designed to represent both hydrothermally altered (MacArthur) and unaltered (Mason Butte) areas, as well as one site in Alluvium.

A. DESCRIPTION OF TEST SITES

Mason Butte (1): a small butte (1.4 × 2.8 km) (plate 6) north of the Yerington town site. Test site 1 is an area of unaltered Jurassic granodiorite

pebble-cobble soil surrounded by greasewood and shadescale phreatophyte vegetation.

Mason Butte (2): (plate 7) a small jagged outcrop (2 × 5 m) of Jurassic unaltered granodiorite.

Alluvium (3): (plate 8) a medium to fine grain brown to tan soil derived from the Tertiary ignimbrite sequence west of the test site. The vegetation at the site is predominantly greasewood and sagebrush.

MacArthur (4): (plate 8) undisturbed soil at the MacArthur prospect an area of hydrothermally altered granodiorite and quartz monzonite.

MacArthur (5): (plate 8) an unvegetated flat mound created by trenching of the area of hydrothermally altered granodiorite, quartz monzonite porphyry, and andesite cobbles.

B. THERMAL DATA

Data collected for the five test sites are given in Table 7, all temperature values are given in degrees C. A plot of the diurnal temperature profile is given in Figure 12.

In an attempt to establish a calibration site large enough to be applicable to the HCMM system, data was collected from the large (0.5 × 1.5 km) cooling ponds for the Fort Churchill Power Station. The power station is located approximately 15 km north of the Yerington test sites in Mason Valley. Plant overflow and inflow water temperatures were supplied for the approximate times of satellite overpass, and are given in Table 8.

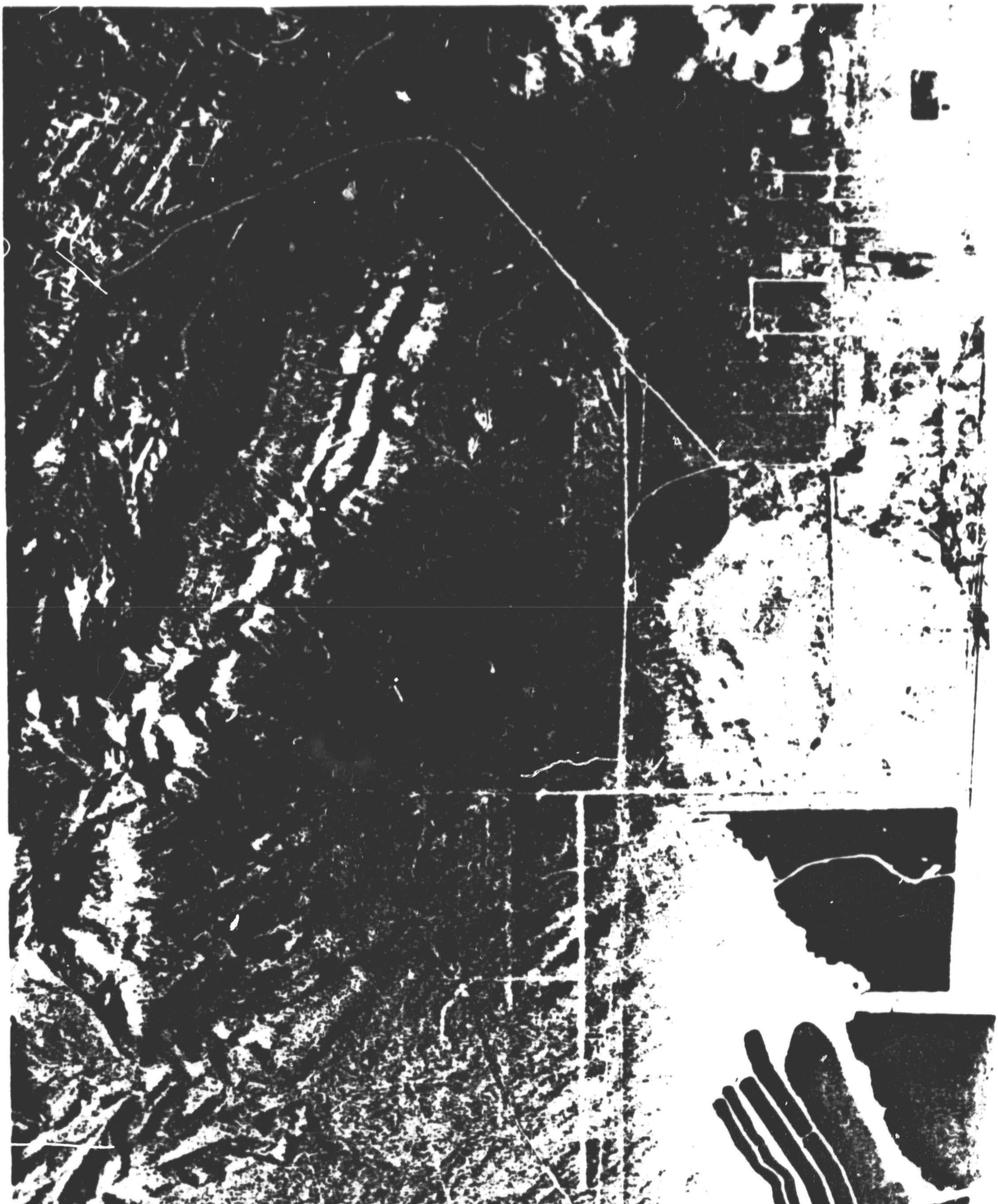

Plate 8

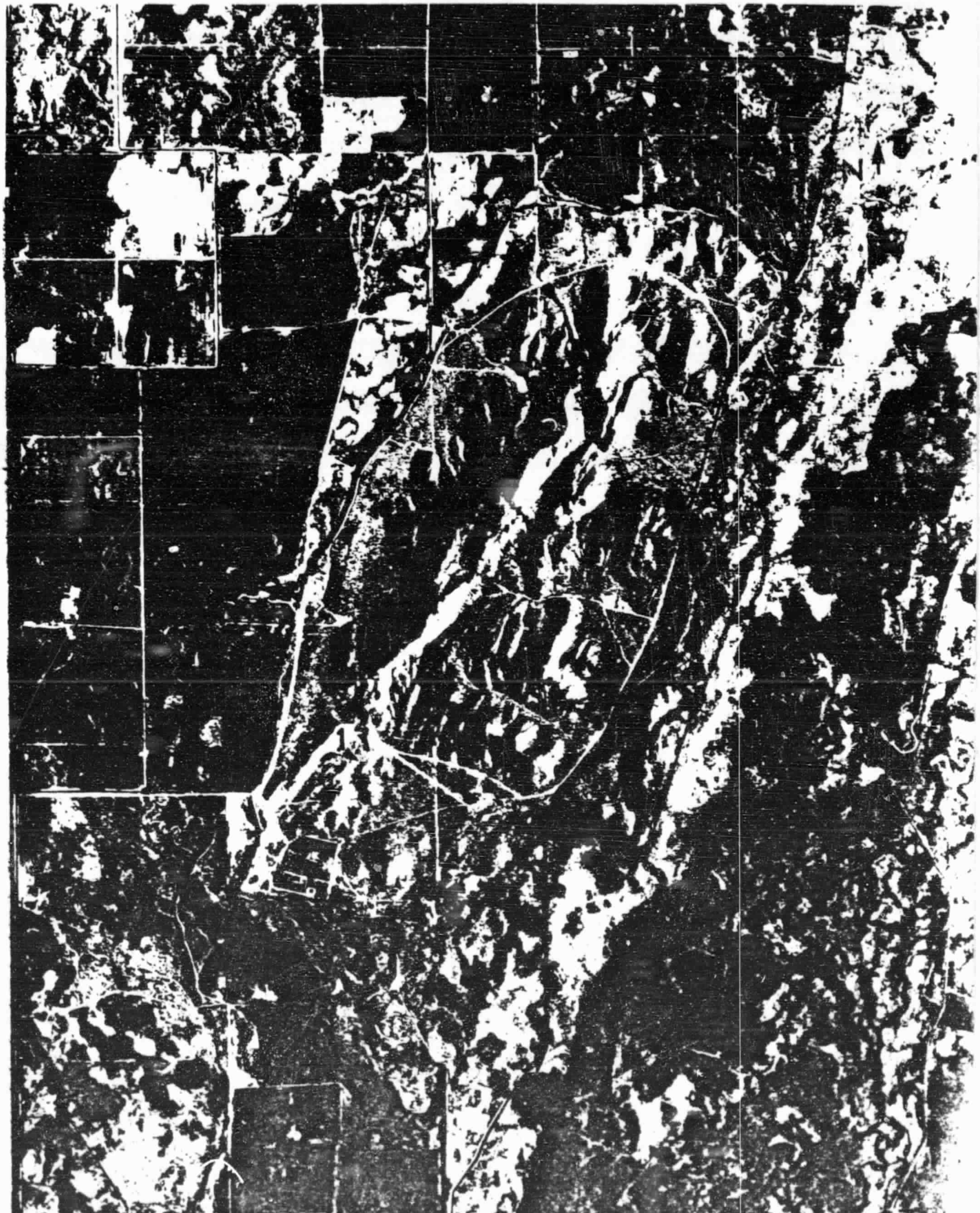

plate 7

TABLE 7

Thermal Data Sheets — Yerington — December 8-9, 1978

Date	Time	PRT-5	Therm ½"	Probe ½"	Probe 2"	Probe 8"	Air Temp	Wind Cloud
Mason Butte Soil (1)								
12/8/78	0812	-12.0		<0	<0	<0	-4	0-2 mph High 10%
	0945	- 4.0	-5.5	<0	<0	<0	-6	0-1 20%
	1115	+ 3.5	-0.5	<0	<0	<0	-1	0-2 30%
	1328	+ 3.5	+2.4	<0	<0	<0	+0.5	0-2 50-60%
	1403	+ 5.0		2.0	<0	<0	-0.5	0-2 80-90%
	1535	0.0		<0	<0	<0	-0.5	0-2 90-100%
Sunset	1619	- 1.5		<0	<0	<0	-3.5	0-2 80-90%
	1725	- 3.0		<0	<0	<0	-4.5	0-2 40-80%
	1735	- 3.5		<0	<0	<0	-4.5	0-2 40-80%
12/9/78	0030	-11.5		<0	<0	+0.2		0 0
	0155	-10.5		<0	<0	+0.8		0-2 0-10
	0209	-10.5		<0	<0	+0.2		0-2 0-10
	0915	- 3.0		<0	<0	<0		0-2 30-40%
	1110	+ 7.5		+2.5	<0	<0		0-2 20%
	1201	+ 7.5		+4.2	<0	<0		0-2 20-40%
	1335	+ 9.0		+6.1	<0	<0		0-2 50-80%
Mason Butte Outcrop (2)								
12/8/78	0812	-11						
	0945	- 5						
	1115	+ 0.5						
	1328	+ 5.5						
	1403	+ 2.0						

TABLE 7 (continued)

Date	Time	PRT-5	Therm ½"	Probe ½"	Probe 2"	Probe 8"	Air Temp	Wind Cloud
Mason Butte Outcrop (2) (cont'd)								
12/8/78	1535	0.0						
	1619	- 2.0						
	1725	- 3.5						
	1735	- 3.5						
12/9/79	0030	-10.0						
	0155	- 9.0						
	0915	- 5.0						
	1110	+ 2.0						
	1201	+ 4.5						
	1335	+ 8.0						
Alluvium Mason Pass (3)								
12/8/78	0836	- 5.5	-8	<0	<0	<0	- 5	0-2 mph 10%
	1005	+ 2.0	-2	<0	<0	<0	- 4	0-1 20%
	1100	+ 8.0	0	<0	<0	<0	0	0-2 20%
	1310	+ 6.5	+1.4	+1.4	<0	<0	+ 0.5	0-2 40-50%
	1420	+ 5.5		+1.2	<0	<0	0	0-2 80-90%
	1517	+ 1.0		+0.1	<0	<0	+ 2.0	0-1 90-95%
	1635	- 0.5		0.0	<0	<0	- 3.0	0-2 90-100%
	1710	- 2.5		<0	<0	<0	- 2.0	0-1 40-80%
	1750	- 5.5		<0	<0	<0	- 2.5	0-2 50%
12/9/79	0048	-10.0		<0	<0	<0	-13.0	0 0
	0137	- 9.0		<0	<0	<0	-12.5	0-2 0-10%

TABLE 7 (continued)

Date	Time	PRT-5	Therm ½"	Probe ½"	Probe 2"	Probe 8"	Air Temp	Wind Cloud
Alluvium Mason Pass (3) (cont'd)								
12/9/79	0224	-10.0		<0°	<0°	<0°	-13.5	0-2 mph 0-10%
	0935	+ 5.5		<0	<0	<0	0.0	0-2 30%
	1055	+ 9.5		+ 0.2	<0	<0	+ 1.5	0-2 30%
	1222	+14.0		+ 2.8	<0	<0	+ 5.5	0-2 25%
	1313	+16.5		+ 3.4	<0	<0	+ 8.0	0-2 40-50%
MacArthur Soil (4):								
12/8/79	0851	- 4.0	-5	<0	<0	<0	- 3.0	0-1 10%
	1021	+ 5.0	+1	<0	<0	<0	- 1.0	0-1 20%
	1047	+ 8.0	-0.5	0.0	<0	<0	- 3.0	0-1 20%
	1300	+ 9.0		+ 3.5	<0	<0	+ 0.5	0-2 40%
	1430	+ 5.0		+ 1.5	<0	<0	- 1.5	0-2 80-90%
	1508	+ 0.5		+ 0.2	<0	<0	- 2.5	0-2 90%
	1645	- 1.5		<0	<0	<0	- 1.0	0-2 90%
	1703	- 2.0		<0	<0	+0.1	- 5.0	0-2 90%
	1800	- 4.0		<0	<0	+0.1		0-2 60%
12/9/79	0058	- 8.0		<0	<0	+0.3		0 0
	0124	- 8.0		<0	<0	+0.2		0-2 0-10%
	0238	- 9.0		<0	<0	+0.2		0-2 0-10%
	0950	+ 2.5		0.0	<0	<0		0-2 40%
	1041	+ 5.0		+ 2.4	<0	<0		0-2 30%
	1235	+ 8.5		+ 6.3	<0	<0		0-2 25%
	1305	+ 7.5		+ 6.7	<0	<0		0-2 40-50%

TABLE 7 (continued)

Date	Time	PRT-5	Therm ½"	Probe ½"	Probe 2"	Probe 8"	Air Temp	Wind Cloud
MacArthur Mound (5):								
12/8/79	0851	- 7.0						
	1021	- 1.0						
	1047	+ 2.0						
	1300	+ 3.0						
	1430	+ 1.5						
	1508	+ 0.5						
	1645	- 2.0						
	1703	- 2.0						
	1800	- 4.0						
12/9/79	0058	- 9.5						
	0124	- 9.5						
	0238	-10.0						
	0950	0.0						
	1041	+ 5.0						
	1235	+ 6.5						
	1305	+ 5.5						

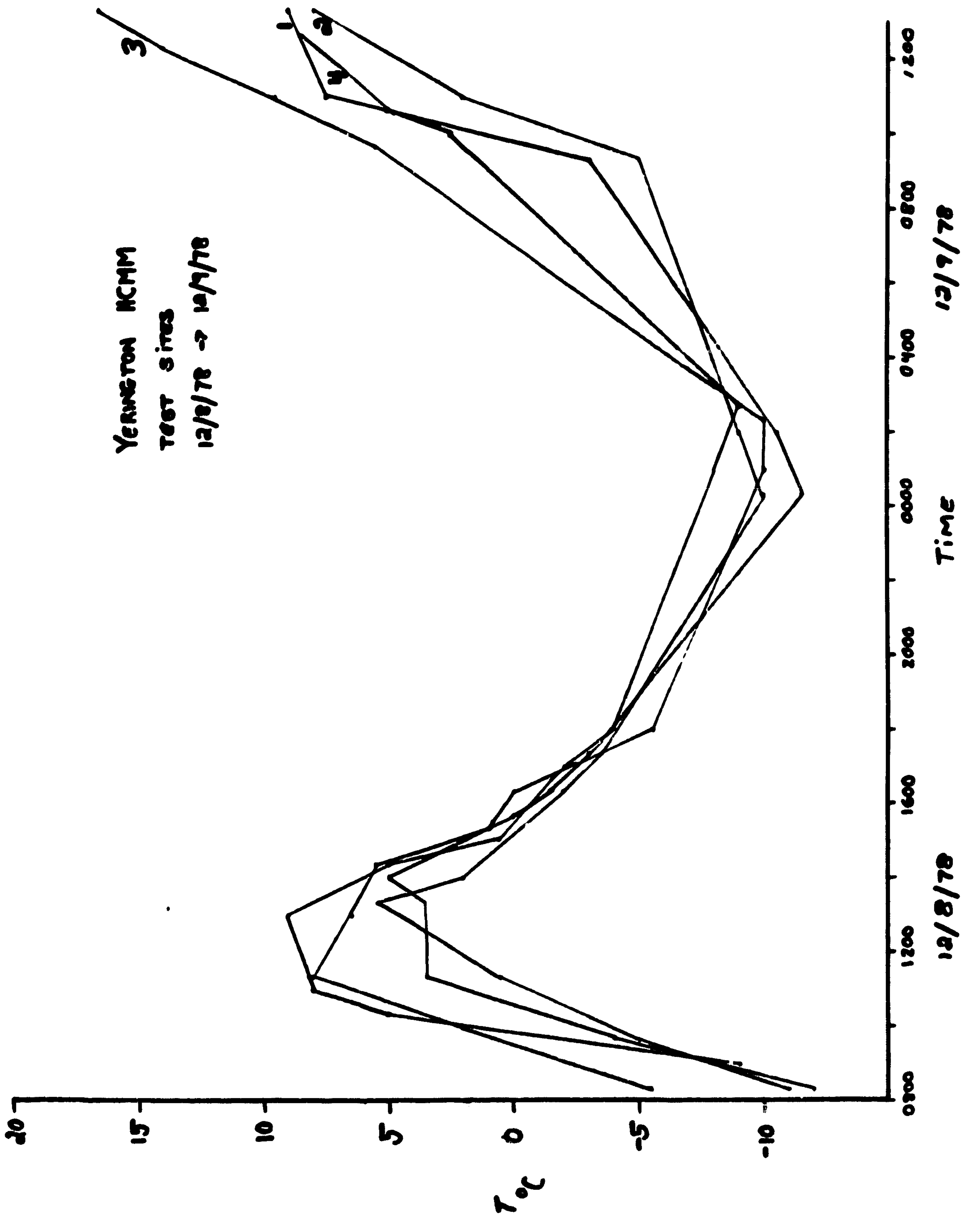
Yerington NCMM
Test sites
12/8/78 → 12/9/78
T °C
20
15
10
5
0
-5
-10
0800
1200
1600
2000
0000
0400
0800
1200
Time
12/8/78
12/9/78
1
2
3
4

TABLE 8

Fort Churchill Power Station Cooling Pond Temperatures

TIME	OUTFLOW (°C)	INFLOW (°C)	MEAN (°C)
0200	23.3	12.8	18.0
1300	31.7	13.9	22.8

C. MODEL RESULTS

Unfavorable weather conditions and a severe lack of time made it impossible to transport the Ottawa sand standard to the field during this mission. Therefore, the meteorological input variables could only be estimated. Cloud cover was visually estimated during the measurement program and day and night sky temperatures were evaluated employing the Van Wijk and Shulte equation. The albedo of each site was determined from previous measurements of the areas with the Exotech radiometers.

The SURTEMP model was run to estimate the thermal inertia of the Mason Butte and MacArthur test sites employing the input variables given in Table 9.

The standard error of the fit between the observed and model calculated diurnal temperatures for the anticipated range (0.020-0.060 cal cm^{-2} • $°C^{-1}$ $sec^{-1/2}$) of thermal inertia values was then calculated. The results indicated the thermal inertia of the test sites could be estimated with 15% with values of 0.035 for the MacArthur site and 0.050 for the Mason Butte site. The standard error of the fit for the MacArthur site is

6.25 degrees and is 3.96 degrees for the Mason Butte site.

TABLE 9

Input Variables for the December 1978 Mission

	Mason Butte	MacArthur
Albedo	0.22	0.27
Emissivity	0.90	0.90
Cloud Cover	0.50	0.50
Latitude	38.90	38.90
Solar Declination	22.70	22.70
Dip	0.0	0.0
Strike	0.0	0.0
Sky Temperature	220.0K	220.0K

A value of 0.050 for the granodiorite at Mason Butte is considered reasonable in light of previously published (Lyon, 1974) values for similar rock compositions. The value of 0.035 for the altered granodiorite and quartz monzonite soil is within 15% of the value determined during the August 1977 field mission. This is considered to be within experimental and model limitations due to the quite variable meteorological conditions and the associated uncertainty of relating these conditions to model input variables during this mission.

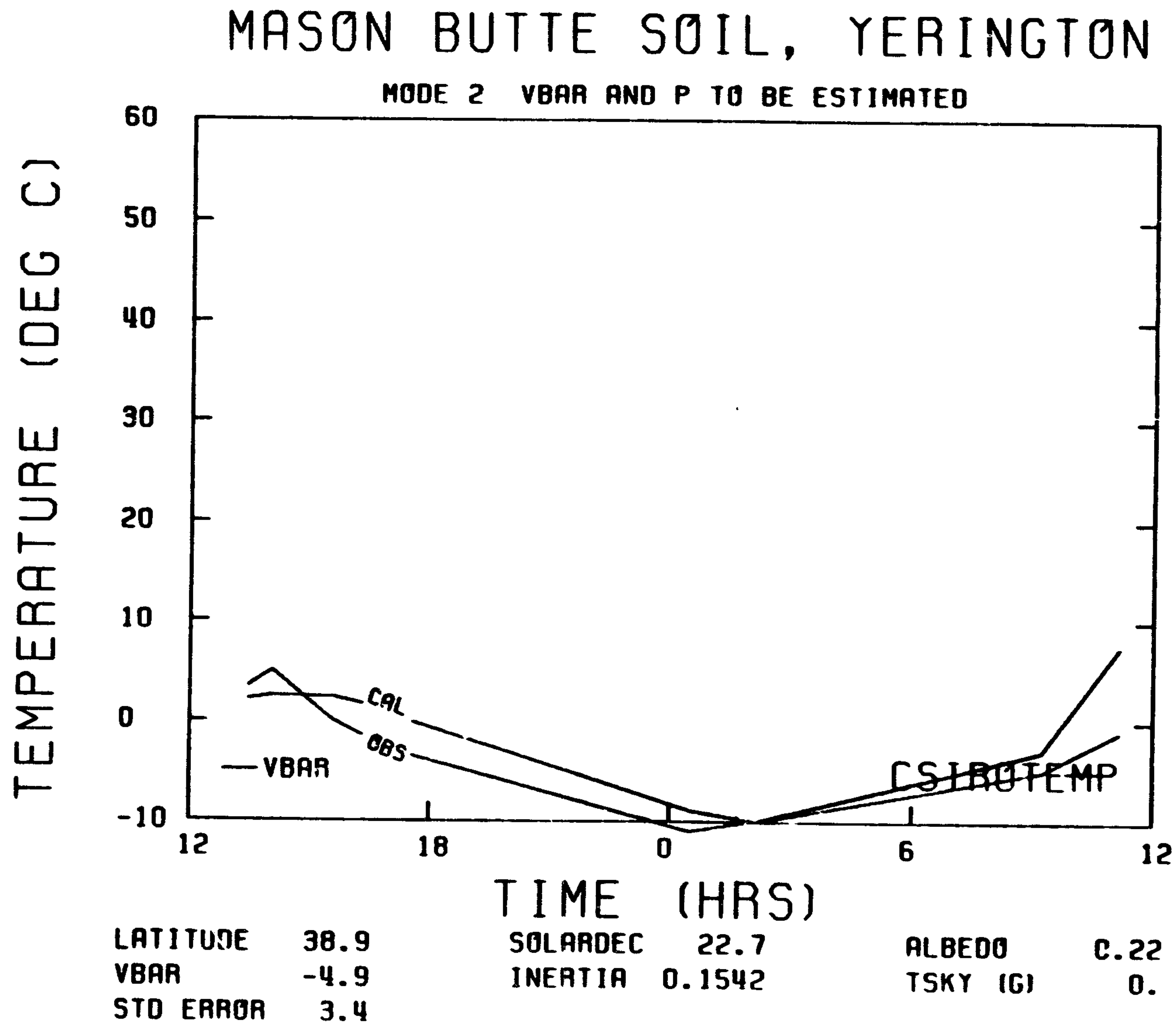

FIGURE 15d. Yerington Area, Mason Butte Soil, Mode 2--CSIROTEMP Ave.Temp and Thermal Inertia to be estiemted.

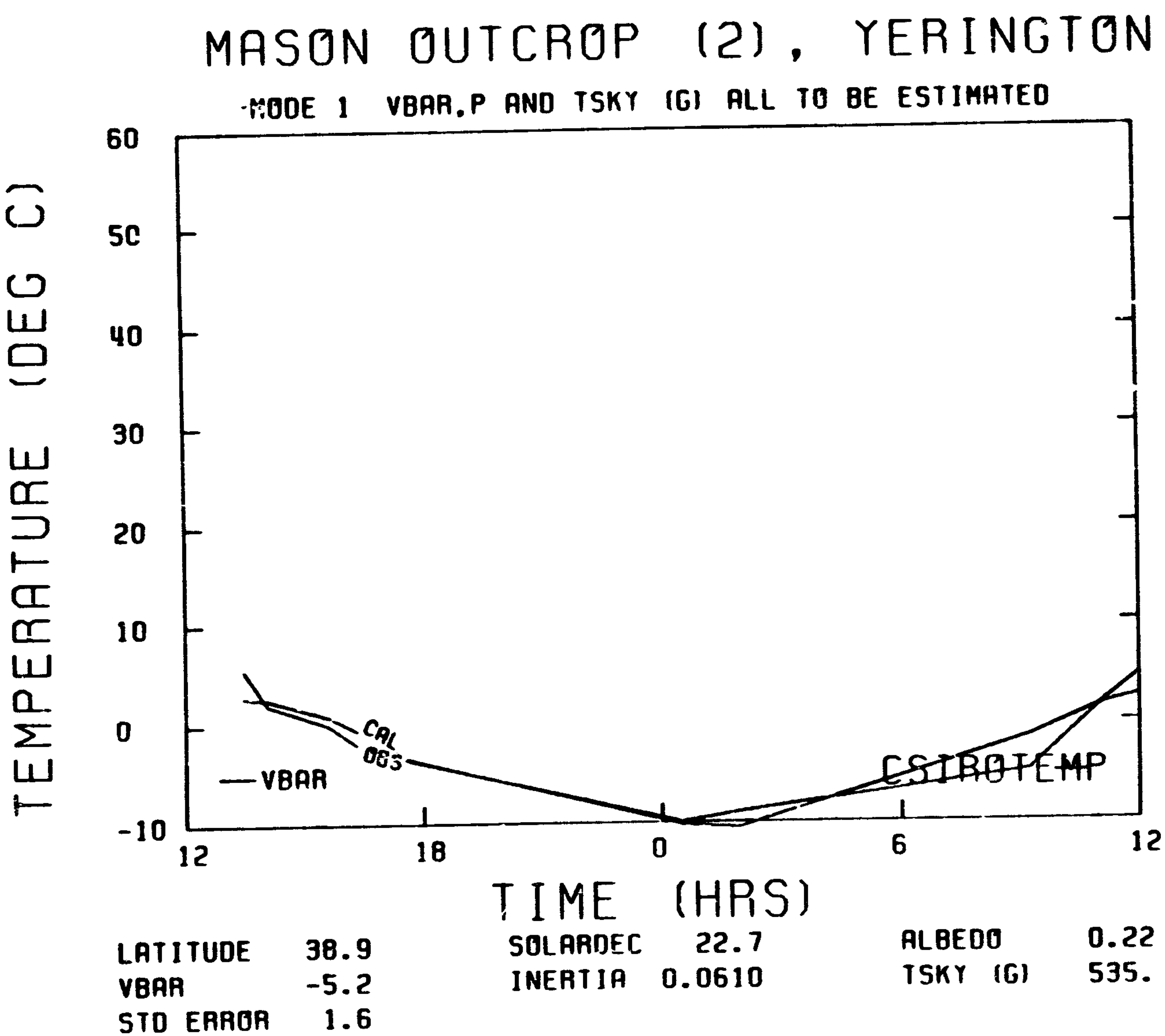

FIGURE 15e Yerington Area, Mason Butte, Granodiorite Outcrop, CSIROTEMP Mode 1-- Ave Temp, Thermal Inertia, and Atmospheric Parameter (G) to be estimated.

V. P-3 (MMS), U-2, AND HCMM DATA INTERPRETATIONS

The chart below describes the data available for the study:

	August 8-9, 1977	May 30, 1978	December 8-9, 1978
Field Measurement	X		X
P-3 (MMS)	X		
U-2	X	X	
HCMM		X	X

The field measurements have been described elsewhere. Following will be an interpretation of the P-3 (MMS), U-2, and HCMM data.

P-3 (MMS) DATA

The P-3 (MMS) flight over Yerington was made on August 8th and 9th to correlate overflight data with three local ground calibration sites. The data obtained by the P-3 (MMS) corresponds to 11 channels ranging from 0.419 to 11.64 μm (channel 11: 7.886 - 11.64 μm). The digital data recorded in magnetic tapes was analyzed to estimate the earth surface temperatures.

Method to Calculate Video Pixels Temperatures

The equation to convert the (pixel) counts to temperature is done using the formula provided by NASA/JSC

$$T_n = \frac{T_{BB(Hi)} - T_{BB(Lo)}}{HKW_{(Hi)} - HKW_{(Lo)}} \quad X_n - HKW_{(Lo)} + T_{BB}(Lo)$$

T_n = Temperature in °C of pixel n

$T_{BB(Hi)}$ = Temperature Black Body — High

$T_{BB(Lo)}$ = Temperature Black Body — Low

$HKW_{(Hi)}$ = Binary Count in Housekeeping Word for Black Body — High

$HKW_{(Lo)}$ = Binary Count in Housekeeping Word for Black Body — Low

X_n = Binary Count of pixel n.

The digital data was extracted and analyzed with the following results:

1) For the day flight (tape 000162, Mission 366) the low and high temperatures for the black bodies were reversed, which means that the data were incorrect and probably useless. The values encountered were:

   Housekeeping Word 923 = 21 (Low Temp BB1)

   Housekeeping Word 926 = 18 (High Temp BB2).

2) For the night flight (tape 00041, Mission 366) the range of temperatures for channel 11 were too widely spread to use in the calculation of pixel temperatures:

   Housekeeping Word 923 = 26 (Low Temp BB1)

   Housekeeping Word 926 = 251 (High Temp BB2).

Deu to the problems described above, it was not possible to obtain meaningful temperatures from the P-3 (MMS) flight to correlate with the ground measurements.

U-2 (HCMR) DATA

Two U-2 aircraft missions were conducted over the test site to correlate overflight data with ground calibration sites. The first mission was

flown in August 8-9, 1977, coincident with the P-3 (MMS) flight. The data obtained by the Heat Capacity Mapping Radiometer corresponds to two channels (visible: 0.5 - 0.7 μm, thermal infrared: 10.5 - 12.5 μm) with a nominal thermal resolution of 0.2°C and spatial resolution of 57 × 57 m.

1. August 8-9, 1977 Flight

Two tapes were received for the August 8-9, 1977 flight: U2-HCMR-VICAR and U2-HCMR-calibrated. The analysis was performed on the U2-HCMR calibrated data. Figure 13 is a "panoramic corrected" DOTPRINT showing part of the Weed Heights near Yerington, Nevada. The DOTPRINT was obtained using the raw numeric data in the thermal infrared channel from the U-2 HCMR calibrated tape (U-2 Flight 77.130, HCM Flight 18). The area inside the square has been enlarged and is shown in Figure 14. The raw numeric data (channel 2) corresponding to the area inside the square is shown in Table 10. The numbers in the figures represent the coordinates of the U2-HCMR calibrated tape. The enlarged area in Figure 14 is part of a water body (tailing pond) in the Yerington mine dump area, for which there is ground truth data. Note that the image (Figures 13 and 14) has been "reflipped horizontally", i.e., rotated from how it was originally taken, and now west is to the left, and east to the right.

In order to analyze the numeric data corresponding to the radiance and temperature for channel 2 and the reflectance for channel 1 (visible), data were extracted from the U2-HCMR calibrated tape corresponding to the area shown in Figure 14 and compared with the IBM output provided by NASA/GSFC. Table 10 lists the raw numerics and calibration data from the U2-HCMR calibrated tape, and Table 11 shows the calibration data from the IBM output. Tables 10 and 11 indicate that there is no correspondence

between these radiance and temperature sets, which means that some problems (not yet clarified) exist in the data. The table, however, does show that there is agreement between the IBM output and the U2-HCMR calibrated tape for the reflectance data in the visible.

The chart below compares the temperatures between the U2-HCMR calibrated tape and the ground measured temperatures, in degrees Kelvin:

STATION	U-2 TEMPERATURE (°K)		GROUND TEMPERATURE (°K)
	NASA/GSFC	IBM Output	
A (water body)	303.28	304.97	295.65 (Hr: 14:41)
B (water body)	312.65	317.01	296.05 (Hr: 14:45)
ΔT	9.37	12.04	0.40

The ΔT for the U-2 data (over water) is too large considering that stations A and B are one pixel apart (see Figure 14). For the Dump Area station the U2-HCMR calibrated tape temperature is 320.86 (NASA/GSFC) and the ground measurement 306.2 (ΔT = 14.66). Figure 15 shows a DOTPRINT with the location of the dump area, and Table 12 gives the data extracted from the U2-HCMR calibrated tape.

2. May 31, 1978

The May 31, 1978 mission was conducted by NASA/ARC without informing us until 6 weeks after. Needless to say we have no ground measurements.

No analysis was performed on the May 31, 1978 mission over the test site, due to the lack of correct calibrations for the data and ambiguity of the data.

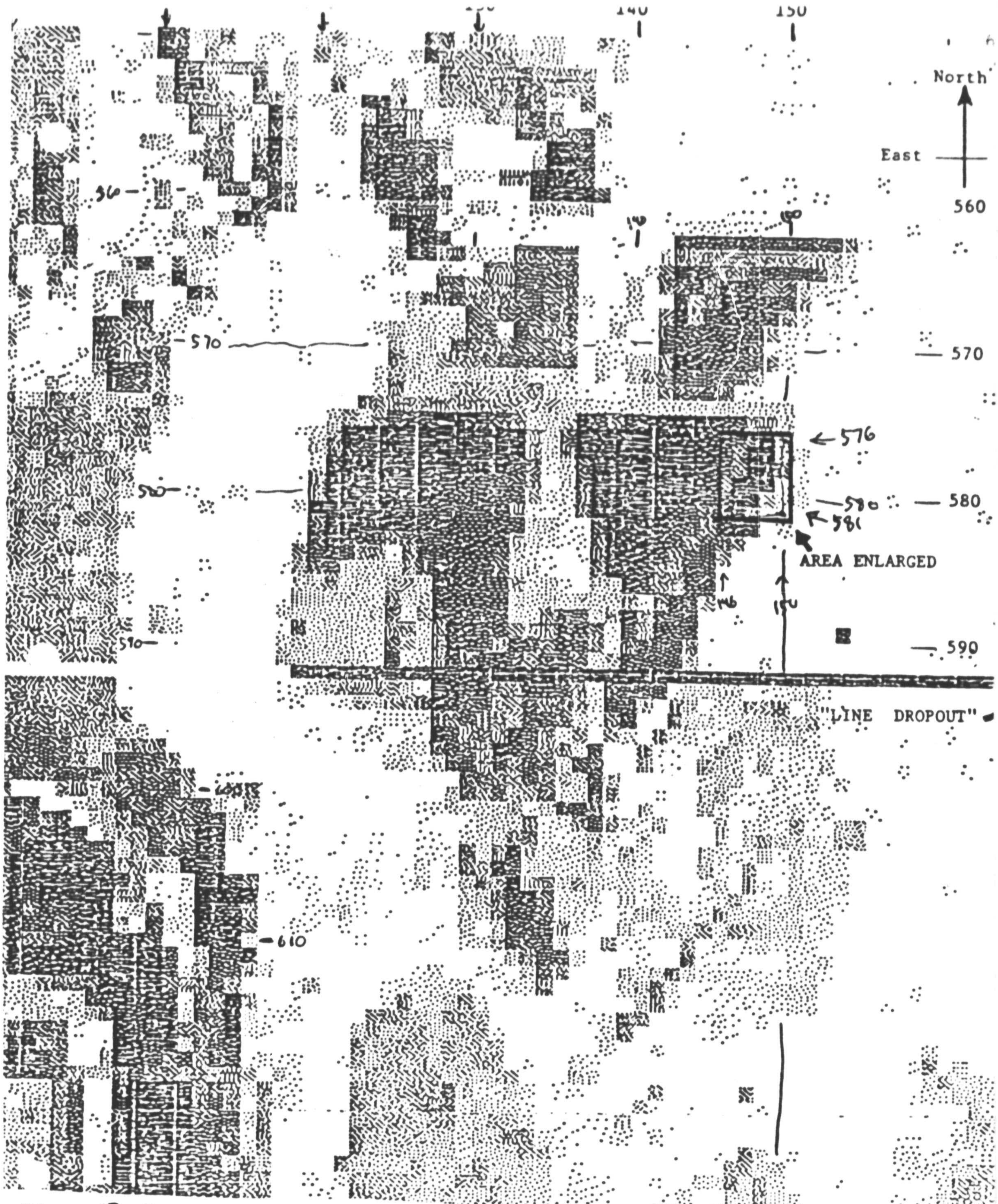

Figure 13 "Panoramic corrected" Dotprint showing part of the Weed Heights in Yerington, Ne
The Dotprint was obtained using raw numeric data in the infrared channel (day) from the U2-
calibrated tape.

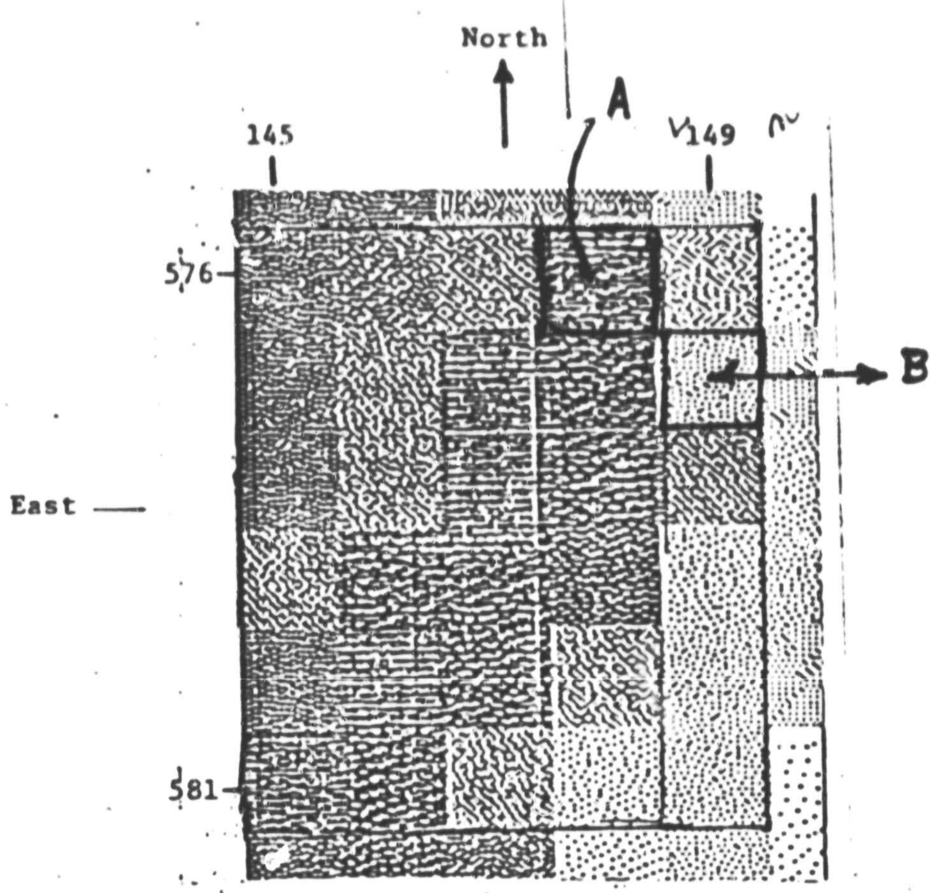

Figure 14 Enlarged "panoramic corrected" Dotprint for part of the tailing pond. The raw numeric data for the infrared channel from Table 10 (U2-HCMR) was used to produce the Dotprint.

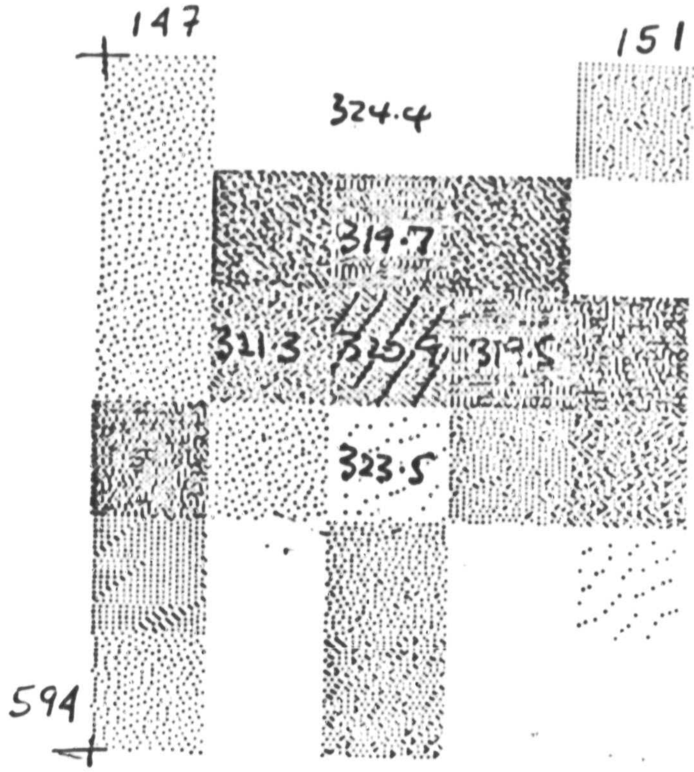

Figure 15. ENLARGED "PANORAMICALLY-CORRECTED DOTPRINT FOR THE DUMP AREA (111)

TABLE 10. Raw Numeric and Calibration Data Extracted from the U2-HCMR

Calibrated Tape

HCM HEAT CAP. MAPPER
U-2 FLIGHT 77.130
HCM FLIGHT 18
YERINGTON, NEVADA

HCMR FLIGHT INSTRUMENT MASTER CALIBRATION TABLES
@75#346

AREA IS 576 TO 581 SCANLINES DOWN FROM THE START=0
145 TO 149 PIXELS IN FROM LEFT EDGE=0

INFRARED BAND

RAW DATA MATRIX (WINDOW)

	COLUMN: (145)				(149)
ROW: (576)	500	512	531	460	605
	501	538	445	468	623
	504	535	446	468	536
	533	464	467	482	640
	502	454	470	591	625
(581)	451	467	588	639	628

CALIBRATION TABLE (EXTRACT)

RAW	BYTE#	OCTAL	RADIANCE	OCTAL	TEMPERATURE
445	1777:2000	7637366552	.00192150	10304563065	302.388
446	1781:1784	7637404102	.00192310	10304563453	302.448
451	1081 ...		.00192110		302.746
454	1813 ...		.00193590		302.926
460	1837		.00194550		303.283
464	1853		.00195190		303.521
467	1865		.00195670		303.699
468	1869		.00195830		303.758
470	1677		.00196150		303.877
482	1925		.00198070		304.586
500	1997		.00200950		305.642
501	2001		.00201110		305.700
502	2005		.00201270		305.759
504	2013		.00201590		305.876
512	2045		.00202870		306.342
531	2121		.00205910		307.443
533	2129		.00206230		307.558
535	2137		.00206550		307.673
536	2141		.00206710		307.731
538	2149		.00207030		307.840
588	2349		.00215030		310.694
591	2361		.00215510		310.863
605	2417		.00217750		311.649
623	2489		.00220630		312.653
625	2497		.00220950		312.765

TABLE 10. (continued)

CALIBRATION TABLE (EXTRACT)

RAW	BYTE#	RADIANCE	TEMPERATURE
628	2509	.00221430	312.932
639	2553	.00223189	313.541
640	2557	.00223349	313.596

VISIBLE BAND

RAW DATA MATRIX (WINDOW)

	COLUMN: (145)				(149)
ROW: (576)	242	294	298	250	307
	246	303	250	246	307
	263	311	250	242	268
	311	263	246	250	316
	285	250	242	290	368
(581)	255	246	294	350	398

CALIBRATION TABLE (EXTRACT)

RAW	BYTE#	REFLECTANCE
242	965	.231
246	981	.235
250	997	.239
255	1017	.244
263	1049	.252
268	1069	.257
285	1137	.274
290	1157	.279
294	1173	.283
303	1209	.292
307	1225	.296
311	1241	.300
316	1261	.305
350	1397	.339
368	1469	.357
398	1589	.387

TABLE 11. Calibration Data from IBM Output (NASA/GSFC)

HCMR FLIGHT MASTER CALIBRATION TABLES
NAME= @76#089
LENGTH=1024 ELEMENTS

TABLE GENERATION PARAMETERS

INFRARED			VISIBLE		
LOCATION	BASE VALUE	INCREMENT	LOCATION	BASE VALUE	INCREMENT
2	1.0294E-03	2.1000E-06	11	0.0	1.0000E-03

INFRARED BAND

INDEX	RADIANCE	TEMPERATURE
445	.0019597	303.8103
446	.0019618	303.8879
451	.0019723	304.2761
454	.0019786	304.5083
460	.0019912	304.9717
464	.0019996	305.2798
467	.0020059	305.5105
468	.0020080	305.5874
470	.0020122	305.7407
482	.0020374	306.6577
500	.0020752	308.0220
501	.0020773	308.0974
502	.0020794	308.1726
504	.0020836	308.3232
512	.0021004	308.9241
531	.0021403	310.3408
533	.0021445	310.4890
535	.0021487	310.6372
536	.0021508	310.7112
538	.0021550	310.8591
588	.0022600	314.5090
591	.0022663	314.7251
605	.0022957	315.7295
623	.0023335	317.0110
625	.0023377	317.1526
628	.0023440	317.3650
639	.0023671	318.1411
640	.0023692	318.2114

VISIBLE BAND

INDEX	REFLECTANCE
242	0.231
246	0.235
250	0.239
255	0.244
263	0.252
268	0.257
285	0.274
290	0.279
294	0.283
303	0.292
307	0.296
311	0.300
316	0.305
350	0.339
368	0.357
398	0.387

ORIGINAL PAGE IS
OF POOR QUALITY

TABLE 12. U2-HCMR Calibrated Tape, Second Version, Flt 18 (Day) 5 by 5 Window, Calibration Site is Approximately at the Center of the Window or Right or Left One Pixel. (Possibly Even in Any of Middle 3 Rows, Any of 5 Pixels)

Note, All Row Coordinates are From Top-Line at Zero. All Pixel Coordinates are From Left-Pixel at One, as Per Documentation of Tape Format. (Indicated by Upper Left Corner=ULC)

INFRARED CHANNEL
FORMAT: TOP-RAW NEXT=INDEX NEXT=RADIANCE BOTTOM=TEMPERATURE

(0) ULC	(1)147	148	149	150	151	
589	705	747	730	721	692	raw
	2820	2988	2920	2884	2768	index
	.00250570	.00259390	.00255820	.00253929	.00247840	radiance
	322.71655	325.56055	324.41553	323.80615	321.82593	
590	707	647	661	645	747	
	2828	2588	2644	2580	2988	
	.00250989	.00238390	.00241330	.00237970	.00259390	
	322.85327	318.70288	319.68140	318.56274	325.56055	
591	705	685	678	659	667	
	2820	2740	2712	2636	2668	
	.00250570	.00246370	.00244900	.00240910	.00242590	
	322.71655	321.34424	310.86108	319.54199	320.09863	
592	666	705	717	692	685	
	2664	2820	2868	2768	2740	
	.00242380	.00250570	.00253090	.00247840	.00246370	
	320.02930	322.71655	323.53442	321.82593	321.34424	
593	690	726	695	731	717	
	2760	2904	2780	2924	2868	
	.00247420	.00254980	.00248470	.00256030	.00253090	
	321.68848	324.14502	322.03198	324.03198	323.53442	

VISIBLE CHANNEL
FORMAT: TOP=RAW NEXT=INDEX BOTTOM=REFLECTANCE

(0) ULC	(1)147	148	149	150	151
589	385	363	359	359	372
	1540	1452	1436	1436	1488
	.374	.352	.348	.348	.361
590	372	389	398	385	372
	1488	1556	1592	1540	1488
	.361	.378	.387	.374	.361
591	398	394	394	389	402
	1592	1576	1576	1556	1608
	.387	.383	.383	.378	.391

TABLE 12 (continued)

592	389	381	363	372	389
	1556	1524	1452	1488	1556
	.378	.370	.352	.361	.378
593	385	372	381	368	363
	1540	1488	1524	1472	1452
	.374	.361	.370	.357	.352

HCMM DATA

The main reason to use HCMM data in the present study is to try to discriminate different rock types using thermal parameters, particularly those related to rock density. The HCMM sensor is a two-channel scanning radiometer providing measurements of reflected solar (0.55 to 1.1 μm) and emitted thermal energy (10.5 to 12.5 μm). There are satellite night/day coverage patterns at least once every 16 days at approximately 12-hour intervals. At northern hemisphere mid-latitudes, the crossing times are about 1:30 p.m. and 2:30 a.m. From the nominal orbit altitude of 620 km, the spatial resolution of the infrared channel is approximately 600 by 600 meters at nadir, and the resolution in the reflectance channel is 500 by 500 meters. These values are masked by resampling the data in the data processing, which generates registered data at a 481.5 meter pixel size.

The data obtained by the HCMM are digitized to 8 bits units of energy (255 levels). In this range, the byte (pixel) counts can be converted to temperature using a formula derived from the Planck function and from calibration procedures representing radiometer performance. The pixel counts are converted to temperatures using the formula of Bohse et al., 1979 established according to a performance evaluation of the HCMM:

$$T(I) = K_2/\ln\left[K_1/I - K_3 + 1\right]$$

I = image pixel data value (0-255)

T = temperature in degrees Kelvin

K_1 = 14421.587

K_2 = 1251.15191

K_3 = -118.21378

For a given I value (pixel count) we believe we can calculate the temperature of a surface element in °K (degrees Kelvin) for the range:

I = 0	T = 260°K	t = -13°C
I = 255	T = 340°K	t = +67°C

Interpretation of HCMM-Satellite Registered Surface Temperatures for 30th May, 1978 Night IR (scene A-A0034-10210).

The HCMM night-IR data for May 30, 1978 was analyzed for the study area. The analysis was conducted using (1) the 3-color Grinnell TV-display which allows viewing of selected ranges of digital data to construct false-color composites of the IR channel, and (2) simulated grey-level pictures (DOTPRINT) on a Printronix matrix printer.

Figure 16 is a DOTPRINT at scale 1:250,000 where the cold areas are represented in dark and warm areas in white with grey-levels in between. The test-site corresponding to the Yerington mine is clearly identified in the DOTPRINT with the symbol **Y D**

Figure 17 is a density-sliced DOTPRINT at 1:250,000 scale with an increment of 0.38°C between each class. There are five classes represented. All the rest (cool areas) is white. The differences in temperature for the terrain in the Yerington mine are from warmer to cooler:

Range in °K	Terrain
281.08 - 280.70	Tailing Ponds — water
279.56 - 279.18	Rock Dumps
278.80 - 278.42	Waste rock

Figure 18 is a density-sliced DOTPRINT at 1:250,000 scale. Class A represents temperatures from 287.5 °K to 281.8 °K and correspond to the warmer areas (water). Class B represent temperatures from 281.4 °K to

LINE	PIXEL	ID		VIS	DIR	NIR	DEL T	T. I.	DIR/DEL T
POWER STATION COOLING PONDS MASON VALLEY, YERINGTON DISTRICT									
367	682	2	POWR	27.0	109.0	35.0	122.0	54.0	0.893
367	683	2	POWR	29.0	106.0	38.0	116.0	58.0	0.914
367	684	2	POWR	39.0	119.0	31.0	136.0	43.0	0.875
367	685	2	POWR	42.0	134.0	26.0	155.0	34.0	0.865
368	682	2	POWR	26.0	109.0	36.0	121.0	55.0	0.901
368	683	2	POWR	29.0	110.0	41.0	116.0	57.0	0.948
368	684	2	POWR	39.0	134.0	33.0	147.0	38.0	0.912
368	685	2	POWR	47.0	146.0	27.0	165.0	31.0	0.885
369	682	2	POWR	33.0	116.0	31.0	133.0	45.0	0.872
369	683	2	POWR	33.0	124.0	32.0	139.0	42.0	0.892
369	684	2	POWR	41.0	140.0	31.0	155.0	35.0	0.903
369	685	2	POWR	47.0	147.0	27.0	166.0	31.0	0.886
LEACH PONDS AND GRANODIORITE WASTE DUMPS, YERINGTON MINE									
386	665	1	DUMP	34.0	118.0	40.0	124.0	50.0	0.952
386	666	1	DUMP	41.0	125.0	39.0	132.0	44.0	0.947
386	667	1	DUMP	44.0	125.0	40.0	131.0	44.0	0.954
386	668	1	DUMP	45.0	121.0	35.0	133.0	43.0	0.910
386	669	1	DUMP	42.0	123.0	32.0	138.0	41.0	0.891
387	665	1	DUMP	28.0	107.0	42.0	112.0	61.0	0.955
387	666	1	DUMP	39.0	109.0	43.0	113.0	57.0	0.965
387	667	1	DUMP	44.0	110.0	44.0	113.0	56.0	0.973
387	668	1	DUMP	44.0	116.0	39.0	124.0	48.0	0.935
387	669	1	DUMP	41.0	135.0	35.0	146.0	38.0	0.925
388	665	1	DUMP	23.0	101.0	38.0	111.0	64.0	0.910
388	666	1	DUMP	41.0	97.0	40.0	105.0	64.0	0.924
388	667	1	DUMP	58.0	107.0	40.0	114.0	50.0	0.939
388	668	1	DUMP	57.0	112.0	39.0	120.0	47.0	0.933
388	669	1	DUMP	49.0	127.0	37.0	136.0	40.0	0.934
389	665	1	DUMP	52.0	116.0	37.0	126.0	44.0	0.921
389	666	1	DUMP	57.0	114.0	39.0	122.0	45.0	0.934
389	667	1	DUMP	67.0	114.0	40.0	121.0	43.0	0.942
389	668	1	DUMP	63.0	118.0	38.0	127.0	41.0	0.929
389	669	1	DUMP	52.0	128.0	37.0	137.0	39.0	0.934
390	665	1	DUMP	50.0	120.0	38.0	129.0	44.0	0.930
390	666	1	DUMP	54.0	116.0	40.0	123.0	46.0	0.943
390	667	1	DUMP	60.0	118.0	40.0	124.0	43.0	0.952
390	668	1	DUMP	60.0	124.0	39.0	131.0	40.0	0.947
390	669	1	DUMP	47.0	135.0	36.0	144.0	37.0	0.937
391	665	1	DUMP	43.0	119.0	38.0	128.0	46.0	0.930
391	666	1	DUMP	41.0	115.0	42.0	119.0	51.0	0.966
391	667	1	DUMP	45.0	128.0	43.0	130.0	44.0	0.985
391	668	1	DUMP	45.0	137.0	40.0	142.0	39.0	0.965
391	669	1	DUMP	45.0	135.0	36.0	144.0	38.0	0.937
392	665	1	DUMP	41.0	127.0	38.0	135.0	43.0	0.941
392	666	1	DUMP	38.0	120.0	39.0	127.0	47.0	0.945
392	667	1	DUMP	46.0	130.0	40.0	135.0	41.0	0.963
392	668	1	DUMP	45.0	134.0	38.0	141.0	39.0	0.950
392	669	1	DUMP	42.0	124.0	35.0	136.0	42.0	0.912

HCMM REGISTERED TAPES RECEIVED TO NOV 1980

ORDERED	RECEIVED	COMMENTS
A-0034 31 May 1978	A-0024 20 May 1978 (received Aug 1980)	SITE WAS ON TAPE EDGE
A-0087 27 July 1978	A-0082 22 July 1978 (received Aug 1980)	SITE NOT ON TAPE
A-0226 8 Dec 1978	A-0226 8 Dec 1978 (received Nov 10,1980)	SITE UNDER CLOUD

278.0 °K and correspond to areas surrounding the water bodies, the Yerington mine, etc. Class C are temperatures from 277.6 °K to 273.8 °K. All the rest (cooler areas) are represented in white. Vegetation and high topographic areas are included in Class C and in white.

The following chart summarizes the quality of the data used in the study:

	August 8-9, 1977	May 30, 1978	December 8-9, 1978
Field Measurements	Good	None taken	Poor due to weather conditions (freezing)
P-3(MMS)	Black bodies Reversed Temp. problems	----	----
U-2 HCMR	Calibration Problems	Calibration Problems	----
HCMM	(Not Launched Yet)	Good	Poor (no information contained in data)

Analysis of the chart indicates that the field measurements corresponding to August 7-8, 1977 and the HCMM satellite data corresponding to May 30, 1978 are the only data sets of use for the present study.

VI. CONCLUSIONS

This study relates an attempt to match the HCMM and U2HCMR-derived temperature data over two test sites (over very <u>local</u> size) to similar data collected in the field at nearly the same times. Considerable logistical problems were encountered. The results indicate that HCMM investigations (using resolution cells of 500 m, or so) are best conducted with areally-extensive sites, rather than point observations. The DAY-VIS imagery is of excellent quality, and has considerable usefulness for GEOLOGY, especially for structural (lineament) studies. For these purposes one does not need the Day-Night registered imagery, except that as a single product, not to be used for further calculations, the DELTA-T imagery is most useful, again for structural geology. Our attempts to register the ground-observed temps. (even for 0.5 sq. mile targets) were unsuccessful, due to the excessive pixel-to-pixel noise on the HCMM data.

Several computer models were explored, and related to changing of the values of thermal parameters, with observed data. Unless quite complex models, with many parameters which can only be observed (perhaps not even measured!) under remote sensing conditions (e.g. roughness, wind shear, etc.) the model outputs do not match the observed data. Empirical relationships may be most readily studied.

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APPENDIX 1: DATA LISTS

The following pages contain the data collected from the soil temperature probes, sol-a-meter, net radiometer, PRT-4 and PRT-5, air temperature sensors, psychrometers, anemometers, and cloud cover observations.

The data is also labeled except for some of the PRT results. The top row for each time in the sandbox and spike data sheets show five voltage readings taken over a short period of time followed by the average of these voltages. The second row under column 1 is the temperature reading from the PRT-5 direct readout dial during the first measurement. The number under AVRG. in the second row is the temperature corresponding to the average millivolt reading.

PRT-4 measurements were made at the MacArthur station, but not until 2100, 8 August 1977 because of operational problems. All readings were recorded in degrees F. The second row under AVRG. is simply the average in °C. Several readings are listed as greater than 43.3°C. This is a result of the surface temperature exceeding the range of the PRT-4.

WK & KL

ANACONDA DUMP SITE - SOIL PROBES IN SANDBC
"DSB"
AUGUST 8-9, 1977

THERMAL DATA SHEET

SITE	DATE	TIME	DEPTH OF PROBES °C #1 -16"	#2 -8"	#3 -4"	#4 -2"	#5 -1/2"	#6 -1"	#7 1/2"	#8 0"	AIR +2"	+24"	°F WET	°F DRY	% CLOUD COVER	VOLTS NET RADIOMETER	WIND M/S	PRT-5mV 1	2	3	4	5	AVG °C
DSB	8-8-77	12:10	27.3	25.1	24.3	28.8	30.5	34.3	38.1	35.8	31.0	26.8	55.0	81.0	0	+.001	0-2	505	612	580	595	600	578m
																		31.5					30.8
"	"	12:36	27.2	25.1	24.9	30.2	31.9	35.8	39.9	—	31.3	26.8			0	+.001	0-3	574	615	599	564	560	582m
																		31.5-	32.5				30.9
"	"	13:12	27.2	25.1	26.1	31.9	33.8	37.4	40.7	46.2	35.4	29.2	53.5	81.5	0	+.001	0-3	674	683	602	630	650	648m
																		33-34					33.1
"	"	13:48	27.2	25.2	27.3	33.7	35.6	39.0	42.4	44.2	36.2	30.5	55.0	86.5	0	+.001	0-3	647	659	647	655	635	649m
																		34-34.5					33.2
"	"	14:15	27.2	25.3	27.7	34.3	36.2	39.6	43.3	46.2	36.2	30.5	54.4	84.8	0	+.001	4-5	615	640	630	610	630	625m
																		33-	34.5				30.4
"	"	15:12	27.1	25.5	29.2	35.6	37.3	40.0	41.6	44.7	35.0	31.2	56.2	90.0	0	+.001	1-3	609	599	643	620	615	617m
																		32.5					32.1
"	"	15:36	27.1	25.6	29.6	35.8	37.4	39.8	41.3	44.1	35.0	31.3	55.4	89.9	0	+.001	3-4	585	575	617	625	640	608m
																		31.9-	33.5				31.8
"	"	16:12	27.1	25.9	30.3	35.9	37.1	38.8	39.8	43.0	34.5	30.3	54.0	85.0	0	+.001	4.5	536	545	500	530	553	533m
																		30-31					29.3
"	"	16:48	27.1	26.2	30.7	35.8	36.7	37.7	37.4	38.1	35.0	30.3	56.1	88.0	0	+.000	6-7	490	500	540	526	520	515m
																		29-31					28.7
"	"	17:24	27.0	26.4	31.0	35.2	35.7	35.9	35.1	36.3	34.0	29.9	57.0	87.0	0	-.000	5-6	448	432	470	500	510	472m
																		27.5					27.2
"	"	18:00	27.0	26.7	31.1	34.3	34.5	34.2	32.9	34.2	34.0	31.0	56.0	86.0	0	-.000	0-2	395	365	384	371	402	381m
																		24.5-	25.0				24.1
"	"	18:36	27.0	27.0	31.1	33.3	33.2	32.4	30.5	30.2 / 37.0	31.5	29.5	55.0	85.2	0	-.000	3-4	310	330	345	348	377	342m
																		23.5-	24.5				22.7
"	"	19:12	27.0	27.2	30.9	32.2	31.8	30.6	28.1	27.2	29.0	27.6	55.2	82.6	0	-.000	4.5	265	260	252	271	268	263m
																		20.5-	21.0				19.9
"	"	19:48	27.0	27.5	30.7	31.0	30.2	28.4	25.4	20.5	26.5	25.2	54.6	80.0	0	-.001	0-2	186	189	197	196	195	193m
																		17.5-	18.0				17.4
"	"	20:24	27.0	27.6	30.3	29.4	28.4	26.2	23.2	22.3	25.0	25.0	57.7	79.0	0	.001	0-2	165	162	157	155	156	159m
																		16.5					16.1
"	"	21:00	27.0	27.9	29.8	28.1	27.0	24.8	21.9	21.3	24.2	24.2	51.5	77.3	0	.001	0-2	140	146	154	159	160	152m
																		16.0-	16.5				15.3

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ANACONDA DUMP SITE-SOIL PROBES IN SANDBOX
"DSB"
AUGUST 8-9, 1977

THERMAL DATA SHEET

SITE	DATE	TIME	DEPTH OF PROBES °C #1 -16"	#2 -8"	#3 -4"	#4 -2"	#5 -1½"	#6 -1"	#7 -½"	#8 0"	AIR +2"	AIR +24"	°F WET	°F DRY	% CLOUD COVER	NET RADIOMETER	WIND	PR mV °C 1	2	3	4	5	AVG.
DSB	8-8-77	21:36	27.1	28.0	29.2	27.0	25.8	23.5	20.6	20.2	23.0	22.3	50.5	75.0	0	.001	0-2	133	125	133	129	135	131 m
																		15.5 -	16.0				15.1
"	"	22:12	No measurements made since busy refueling generator and talking to foreman.																				—
"	"	22:48	27.1	28.1	28.1	25.3	24.0	21.9	19.3	19.4	22.5	22.5	49.7	74.5	0	.001	0-2	097	102	106	098	109	102 m
																		14-15					14.0
"	"	23:24	27.1	28.1	27.5	24.5	23.4	21.3	19.0	19.2	22.0	22.0	49.4	73.6	0	.001	1-2	092	099	100	103	112	101 m
																		14.5-	15.0				14.0
"	"	24:00	27.1	28.1	27.0	24.0	22.8	20.8	18.4	18.6	21.0	21.0	49.2	71.5	0	.001	0-2	070	081	086	083	085	81 m
																		13.5-	14.0				13.2
DSB	8-9-77	00:36	27.2	28.0	26.6	23.4	22.2	20.2	17.9	18.2	21.0	21.0	49.0	73.5	0	.0003	0-2	042	057	054	058	060	54 m
																		12-12	5°				12.2
"	"	01:22	27.2	27.9	26.0	22.5	21.3	19.0	16.6	17.7	19.0	18.6	48.1	69.0	0	.0003	0	046	049	053	060	057	53 m
																		12-13					12.1
"	"	01:48	27.2	27.9	25.6	22.0	20.7	18.6	16.4	16.3	19.5	19.0	47.0	67.5	0	.0003	4-5	037	040	043	038	048	41 m
																		11.5 -	12.5				11.7
"	"	02:24	27.2	27.8	25.2	21.6	20.5	18.6	16.6	16.9	19.3	19.5	47.3	68.0	0	.0003	0-2	040	036	045	040	048	42 m
																		11-12					11.7
"	"	03:00	27.3	27.7	24.8	21.2	20.0	18.0	15.8	15.8	18.4	17.8	46.8	66.7	0	.0003	0-2	010	014	016	014	016	14 m
																		11					10.6
"	"	03:36	27.3	27.5	24.4	20.6	19.6	17.8	15.9	16.1	17.8	17.0	46.0	63.0	0	.0003	0-2	750	770	790	770	790	770
																		8-8.5					7.4
"	"	04:12	27.3	27.4	24.1	20.2	19.1	17.0	14.4	14.4	17.0	16.0	45.9	63.7	0	.0003	0	740	740	750	760	740	750
																		7-7.5					6.7
"	"	04:48	27.3	27.3	23.7	19.7	18.5	16.2	13.6	13.5	16.4	15.4	46.0	60.3	0	—	0-2	700	710	690	710	700	700
																		5.5-6					5.2
"	"	05:24	No measurements made due to oversleeping. Zzzzz...										—		—	—	—						
	SUN	RISING																					
"	"	06:00	27.4	26.9	22.8	18.4	17.2	15.0	12.6	13.0	15.4	15.0	45.5	62.2	0	.0002	0	710	720	730	720	710	720
	SUN	UP	COMPLETELY	BY	06:19													6.5-	7				5.8
"	"	06:36	27.4	26.5	22.4	18.0	16.8	14.8	13.0	13.6	17.5	16.0	45.0	61.0	$5 \cdot 10^3$	.0002	3-4	780	790	800	790	790	790
																		8.5-	11.0				[illegible]

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THERMAL DATA SHEET

ANACONDA DUMP SITE - SOIL PROBES IN SANDBOX "DSB"

AUGUST 8-9, 1977

SITE	DATE	TIME	DEPTH OF PROBES °C #1 -16"	#2 -8"	#3 -4"	#4 -2"	#5 -1½"	#6 -1"	#7 -½"	#8 -0"	AIR +2"	+24"	°F WET	°F DRY	% CLOUD COVER	NET [illegible]	[illegible]	PRT**, V 1	2	3	4	5	°C [illegible]
DSB	8-9-77	07:12	27.4	26.6	22.0	17.9	16.9	15.6	14.8	15.5	20.8	17.4	46.5	63.9	5*	.0001	0-2	055	050	049	042	051	49m
																		12-12.5					12.0
"	"	07:48	27.4	26.4	21.7	18.2	17.6	17.2	17.5	18.4	24.8	21.0	49.7	68.8	haze 5-10	+.0000	0-2	130	133	128	136	142	133m
																		15-16					15.2
"	"	08:24	27.4	26.2	21.6	19.1	18.8	19.3	20.8	22.1	27.0	22.2	49.3	69.5	haze 5-10	+.0002	0-2	195	210	208	203	218	207m
																		18-19					17.9
"	"	09:00	27.4	26.1	21.7	20.4	20.6	22.8	24.4	25.9	28.0	23.6	52.0	75.9	haze 5-10	+.0004	0-2	288	290	290	297	298	293m
																		21.5	22.0				21.0
"	"	09:36	27.3	25.9	22.0	22.0	22.7	25.0	28.2	29.8 31.8	29.5	24.9	54.5	78.0	5	+.0006	0-2	370	363	375	375	370	371m
																		24-24.5					23.7
"	"	10:12	27.4	25.8	22.5	23.8	24.7	27.7	31.5	34.7	30.0	27.0	55.5	82.9	5-8	+.0009	2-4	470	460	465	480	462	467m
																		27.5	28.0				27.0
"	"	10:48	27.3	25.5	23.2	26.0	27.3	30.8	35.8	37.7	33.2	27.4	56.5	84.5	6-10	+.0010	2-4	536	542	538	553	532	540m
																		30-30.6					29.5
"	"	11:24	27.3	25.5	24.0	28.0	29.5	33.3	37.6	40.0 42.2	33.4	29.3	56.4	83.0	6-10	+.0012	4-8	560	565	578	560	552	563m
																		30.5	31.5				30.3

* Measurement not made at 36 minute interval.

** m = medium range used for PRT-5 meter reading.
L = low range used for PRT-5 meter reading.

*** Voltmeter readings rounded off to tens for all low range values recorded.

CALIB[illegible]

THERMAL DATA SHEET

ANACONDA DUMP SITE - SOIL PROBES IN SPIKE "DSP"
AUGUST 8-9, 1977

SITE	DATE	TIME	DEPTH OF PROBE °C P6-1½"	P5-10"	P4 5½"	P3 -1"	AIR °C	°F WET	°F DRY	% CLOUD COVER	NET RADIO RATE	WIND	PRT-5 medium range 1	2	3	4	5	avg.
DSP	8.8.77	12:15	27.4	27.3	28.5	36.5	29.8 31.6						900	910	915	901	895	104
													41.5 -	43.0				41.7
"	"	12:36	27.4	27.5	29.8 31.3	37.3	32.9						890	915	830	899	895	886
													—					41.1
"	"	13:12	27.5	27.8	31.9	38.0	35.6						960	970	954	965	985	967
													43.44					43.9
"	"	13:48	27.7	28.2	32.5	38.4	34.1						960	980	992	990	970	978
													46.5 -	47.0				44.3
"	"	14:24	27.8	28.6	33.1	39.1	34.3						950	945	960	945	962	952
													43.5					43.4
"	"	15:00	28.0	29.0	33.7	39.5	35.7						929	896	960	965	948	940
													43.5 -	44.0				43.0
"	"	15:36	28.2	29.3 31.4	34.2	39.0	35.5						879	859	885	900	900	885
													41.5 -	42.5				41.0
"	"	16:12	28.4	29.6 31.9	35.6	39.2	35.3						835	775	890	840	850	838
													40 -	42				39.4
"	"	16:48	28.6	30.1 31.9	34.8	38.2	34.0						760	780	770	740	770	764
													37.5					37.0
"	"	17:24	28.9	30.5 32.3	34.8	37.3	33.8						690	693	707	707	685	696
													35 - 36					34.7
"	"	18:00	29.1 34.0	30.7 32.4	34.8	36.4	33.6						638	659	617	645	656	643
													33.5 -	34.5				33.0
"	"	18:36	28.7	32.5	34.6	35.2	32.6						550	540	545	552	574	552
													29.5 -	31				29.9
"	"	19:12	29.4 31.6	32.7	34.2	33.6	28.4						464	487	472	490	489	490
SUN BEHIND SINGATSE RANGE 19:35 - STATION SHADED													28 - 29					27.5
"	"	19:48	29.6 31.5	32.7	33.8	29.9 31.2	26.4						413	405	420	426	409	415
													25.5 -	26.5				25.3
"	"	20:24	29.6 31.6	32.7	33.2	27.9	25.4						391	390	387	378	393	388
													25.0					24.4
"	"	21:00	29.2 31.7	32.6	32.8	26.8	24.0						334	356	355	333	337	343
													23.3 -	24.5				23.3

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ANACONDA DUMP SITE - SOIL PROBES IN SAKE
"DSP"
AUGUST 8-9, 1977

THERMAL DATA SHEET

SITE	DATE	TIME	DEPTH OF PROBES °C #6 -14.5"	#5 -10"	#4 -5.5"	#3 -1"	AIR #1 19.5"	WET	DRY	% CLOUD COVER	NET RADIOMETER	WIND	PRT °C 1	2	3	4	5	AVG
DSP	8-8-77	21:36	29.9 31.8	32.3	30.2 32.2	25.8	23.0						340	356	360	345	341	348
													23-24					22.9
"	"	22:12	No measurements made since busy refueling generator and talking to foreman															—
																		—
"	"	22:48	31.8	32.2	29.4	24.8	22.4						303	309	312	322	306	310
													22-22.5					21.6
"	"	23:24	29.8 31.7	30.0 32.0	29.0	24.6	22.5						279	295	287	289	284	287
													21.5-22					20.8
"	"	24:00	29.8 31.7	29.9 31.8	28.6	24.0	21.5						284	280	287	277	289	283
													21-21.5					20.7
DSP	8-9-77	00:36	29.8	29.6	28.1	23.6	21.2						250	266	269	270	253	262
													20-21					19.9
"	"	01:12	29.7	29.4	27.5	22.5	20.1						231	242	228	238	227	233
													19-19.5					18.9
"	"	01:48	29.5	29.2	27.3	22.2	19.2						231	241	234	230	227	233
													19-19.5					18.9
"	"	02:24	29.4 31.4	28.9	26.9	22.2	20.4						220	230	223	225	234	226
													19-19.5					18.6
"	"	03:00	29.3	28.7	26.7	21.7	18.9						195	202	207	194	207	201
													18-18.5					17.7
"	"	03:36	29.2	28.5	26.3	21.3	18.6						197	200	210	190	187	197
													17.5-18.5					17.5
"	"	04:12	29.0	28.3	26.0	19.7 20.6	17.2						195	199	190	196	202	196
													17-18					17.5
"	"	04:48	28.8	28.1	25.7	20.2 20.9	16.2						185	194	189	190	185	189
	DAWN BEGINS												17-18					17.3
"	"	05:24	No measurements made due to oversleeping										—					
"	"	06:00	28.6	27.5	25.6	19.4	16.2						193	187	195	190	196	19[illegible]
		SUNRISE 06:10											17.5	18				17.3
"	"	06:36	28.5	27.5	24.9	19.6	17.6						193	186	192	201	195	194
													17.5-18					17.4

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THERMAL DATA SHEET

ANACONDA DUMP SITE - SOIL PROBES IN SPIKE
"DSP"
AUGUST 8-9, 1977

SITE	DATE	TIME	DEPTH OF PROBES °C #6 -14½"	#5 -10"	#4 -5½"	#3 -1"					AIR #1 +9½"		WET	DRY	% CLOUD COVER	NET RADIOMETER	WIND	PRT °C 1	2	3	4	5	[illegible]
DSP	8-9-77	07:12	28.4	27.3	24.8	21.6					19.8							220	214	230	225	219	222
																		18.5-	19.5				18.5
"	"	07:48	28.2	27.2	25.0	23.2					24.2							310	315	308	320	326	316
																		22-22.5					21.8
"	"	08:24	28.1	27.1	25.3	25.6					25.9							388	394	382	373	407	389
																		24.5-	25.5				24.4
"	"	09:00	28.0	27.1	25.8	27.8					27.6							495	482	476	480	479	492
																		28	28.5				27.6
"	"	09:36	27.9	27.6	26.2	29.4					28.5							571	587	560	564	560	568
																		31-32					30.4
"	"	10:12	27.8	27.1	26.8	33.0					31.0							650	665	681	666	650	662
																		34-35					33.6
"	"	10:48	27.8	27.2	27.5	34.7					33.2							767	750	748	785	781	766
																		37.5	38.5				37.0
"	"	11:24	27.8	27.2	27.5	34.7					33.2							818	846	810	790	730	799
																		36-40					38.1

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CALIBRATION ✓
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ANACONDA DUMP SITE - AIR PROBES W SEWER PIPE
"DASP"
AUGUST 8-9, 1977

THERMAL DATA SHEET

SITE	DATE	TIME	DEPTH OF PROBES A -31"	B -1.5"	C -7"	D -3"	H -2"	E -1"	AIR F +2"	G +24"	WET	DRY	% CLOUD COVER	NET RADIOMETER	WIND	SOLAR-METER V:
DASP	8-8-77	12:07	28.4	27.8	26.6	28.8	32.9	35.6	24.8	22.4						4.32
"	"	12:36	28.5	27.9	27.1	29.6	33.9	36.3	36.2	33.0						4.41
"	"	13:12	28.5	27.9	27.8	32.6	35.2	36.9	34.2	32.8						4.51
"	"	13:48	28.4	27.8	28.4	33.4	36.7	37.5	36.6	33.6	44.					4.42
"	"	14:24	28.4	27.9	28.9	24.2	37.8	38.7	37.8	36.0						4.30
"	"	15:00	28.4	28.0	29.8	35.1	38.7	39.0	37.5	34.5						3.90
"	"	15:36	28.4	28.1	32.1	35.5	39.0	38.8	38.4	34.2						3.66
"	"	16:12	28.4	28.2	32.6	36.0	39.3	39.6	40.3	34.3						3.12
"	"	16:48	28.4	28.3	33.0	36.2	38.8	38.3	38.7	33.5						2.57
"	"	17:24	28.3	28.5	33.3	36.1	40.0	37.2	37.7	32.8						2.04
"	"	18:00	28.3	28.6	33.5	35.8	37.1	36.0	35.5	32.9						1.44
"	"	18:36	28.2	28.8	33.6	35.4	36.2	34.8	34.6	31.9						0.934
"	"	19:12	28.2	28.8	33.6	34.9	35.1	33.5	31.8	28.0						0.430
		STATION NOW IN SHADE - SUN BEHIND SWEATSE RANGE														
"	"	19:48	28.1	29.0	33.4	34.0	33.3	31.2	25.3	25.8						0.157
"	"	20:24	[illegible]	29.1	33.4	33.2	32.1	27.5	24.2	25.0						0.075
		DARK														
"	"	21:00	28.2	29.4	33.2	32.5	31.3	26.6	23.8	25.4						0.000 DARK VOLTAGE

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THERMAL DATA SHEET

ANACONDA DUMP SITE - AIR PROBES IN SEWER PIPE
"DASP"
AUGUST 8-9, 1977

SITE	DATE	TIME	DEPTH OF PROBES, °C A -31"	B -15"	C -7"	D -3"	H -2"	E -1"			AIR F +2"	G +24"	WET	DRY	CLOUD	NET RADIOMETER	WIND	SOLAR METER: 1	2	3	4	5	6
DASP	8-8-77	21:36	28.2	29.4	33.0	31.8	28.3	25.7			22.5	23.4											
"	"	22:12	Measurement missed due to gas siphoning and talking to foreman																				
"	"	22:48	28.2	29.6	32.5	30.9	27.1	24.7			22.1	22.9											
"	"	23:24	28.2	29.6	32.2	28.2	26.6	24.4			22.2	23.1											
"	"	24:00	28.2	29.6	29.9	27.6	26.1	23.8			21.2	21.9											
DASP	8-9-77	24:36	28.2	29.6	29.6	27.2	25.5	23.3			21.0	22.5											
"	"	01:12	28.2	29.6	29.1	26.5	24.6	22.0			19.2	19.7											
"	"	01:48	28.2	29.6	28.9	26.0	24.2	21.6			20.2	20.6											
"	"	02:24	28.2	29.6	28.6	25.8	24.1	21.8			20.3	21.1											
"	"	03:00	28.3	29.4	28.3	25.4	23.6	21.2			19.8	19.6											
"	"	03:36	28.3	29.4	27.9	24.9	23.1	20.8			17.8	17.8											
"	"	04:12	28.3	29.4	27.7	24.6	22.7	20.1			16.8	17.1											
"	"	04:48	28.3	29.3	27.4	24.2	22.2	19.4			15.8	16.2											
DAWN BEGINS																							
"	"	05:24	Slept through measurement time																				
"	"	06:00	28.9	29.1	26.8	23.3	21.3	18.6	[illegible]		15.5	15.7									[illegible]		
SUNRISE 6:10																							
"		06:36	28.3	29.1	26.6	23.0	21.1	18.[illegible]			17.1	16.7											

WK & KL

ANACONDA DUMP SITE - AIR PROBES IN SEWER PIPE
"DASP"
AUGUST 8-9, 1977

ORIGINAL PAGE IS
OF POOR QUALITY

THERMAL DATA SHEET

SITE	DATE	TIME	DEPTH OF PROBES °C A -31"	B -15"	C -7"	D -3"	H -2"	E -1"			AIR F +2"	G +24"	WET	DRY	% CLOUD COVER	NET RADIOMETER	WIND	1	2	3	4	5	AVG.
DASP	8-9-77	07:12	28.4	28.9	26.3	23.0	21.7	20.6			19.4	18.0						SOLAR METER:			0.62		
"	"	07:48	28.4	28.8	26.1	23.3	22.7	22.9			24.2	22.4									1.10		
"	"	08:[illegible]4	28.4	28.7	25.9	23.9	23.9	25.3			26.2	22.8									1.63		
"	"	09:00	28.4	28.6	25.9	24.7	25.5	28.3			32.5	27.0									2.28		
"	"	09:36	28.4	28.5	25.9	25.5	26.9	30.0	[illegible]		30.5	27.3									2.78		
"	"	10:12	28.4	28.4	26.1	26.5	28.2	33.9			35.0	32.0									3.18		
"	"	10:48	28.4	28.3	26.4	27.5	29.5	35.2			35.6	32.1									3.64		
"	"	11:24	28.4	28.2	26.9	28.8	31.0	36.2			37.4	32.0									3.95		

MACARTHUR SITE-AIR PROBES IN SEWER PIPE
"MSP"
AUGUST 8-9, 1977

THERMAL DATA SHEET

SITE	DATE	TIME	DEPTH OF PROBES °C #1 -31"	#2 -15"	#3 -7"	#4 -3"	#5 -2"	#6 -1"	AIR #7 +2"	#8 +24"	°F WET	°F DRY	% CLOUD COVER	THERMOMETER +24"	WIND MPH	PRT °F (°C) 1	2	3	4	5	6
MSP	8-8-77	12:10*	27.4	27.9	25.5	27.8	32.6	34.9	34.2-34.8	33.1	54.0	81.0	0	–	3-4	–	–	–	–	–	–
"	"	12:46*	27.8	28.0	26.2	29.5	33.5	37.5	33.0	30.8-31.1	53.0	80.0	0	–	2-3	–	–	–	–	–	–
LATE DUE TO POOR CONNECTION IN #2 THERMISTOR																					
"	"	13:12	27.6	28.0	26.4	31.0	35.0	37.5	31.0	32.0	54.0	82.0	0	–	0-2	–	–	–	–	–	–
"	"	13:48	27.3	27.5	26.2	32.4	36.8	39.0	31.0-34.5	30.5-31.3	55.0	84.0	0	29.0	0-2	–	–	–	–	–	–
"	"	14:24	27.3	27.3	26.7	34.2	38.5	39.5	33.5	31.3-32.3	54.0	83.0	0	30.0	0-2	–	–	–	–	–	–
"	"	15:00	27.3	27.5	27.4	35.2	39.0	40.0	32.0	30.8-31.5	53.0	82.0	0	30.0	0-2	–	–	–	–	–	–
"	"	15:36	27.3	27.5	28.0	36.0	39.3	39.5	32.5-33.0	31.8-32.3	54.0	84.0	0	30.0	2-3	–	–	–	–	–	–
"	"	16:12	27.3	27.5	28.7	36.0	39.0	39.1	34.0	31.8	55.0	85.0	0	30.5	3-4	–	–	–	–	–	–
"	"	16:48	27.8	28.8	29.2	36.0	36.0	37.0	33.5	31.8	54.0	83.0	0	30.0	5-7	–	–	–	–	–	–
17:24 & 18:00 MEASUREMENTS MISSED WHILE FIXING PRT-4 AT STATION 1. NEEDED INVERTOR																					
"	"	18:25*	27.3	27.6	30.2	35.0	36.1	35.2	29.4	29.8	53.5	83.5	0	29.0	2-3	–	–	–	–	–	–
"	"	18:36	27.3	27.5	30.2	34.6	34.8	34.5	30.5	29.8	53.0	83.0	0	28.5	6-8	–	–	–	–	–	–
SOIL SHADED BY 19:12. AIR PROBES AND THERMOMETER ABOVE GROUND STILL IN SUN																					
"	"	19:12	27.1	27.6	30.2	33.9	32.9	32.7	27.0	27.7	53.0	81.0	0	26.5	5-6	–	–	–	–	–	–
ALL OF THE SENSORS ARE SHADED																					
"	"	19:48	26.9	27.5	30.2	32.7	31.0	30.8	24.0	24.8	52.0	78.0	0	24.0	0	–	–	–	–	–	–
"	"	20:24	26.8	27.5	30.2	31.5	29.0	29.0	23.0	22.8	51.0	76.0	0	24.0	0	–	–	–	–	–	–
SUNSET																					
"	"	21:00	27.3	28.0	30.7	30.5	28.0	27.6	21.5	21.3	49.0	73.0	0	22.0	0	77-79	76-78	75-77	76-78	76-78	77.0 (25.0)
"	"	21:36	27.3	28.0	30.5	29.5	26.8	26.5	21.0	22.3	48.5	70.5	0	22.0	0	74-76	74-76	73-75	74-76	73-75	74.6 (23.7)

* Measurement taken at time other than every 36 minute interval.

MK & SV

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MACARTHUR SITE-AIRPROBES IN SEWER PIPE
"MSP"
AUGUST 8-9, 1977

THERMAL DATA SHEET

SITE	DATE	TIME	DEPTH OF PROBES °C #1 -31"	#2 -15"	#3 -7"	#4 -3"	#5 -2"	#6 -1"	AIR #7 +2"	#8 +24"	°F WET	°F DRY	% CLOUD COVER	THERMOMETER	WIND	BRT °F (°C) 1	2	3	4	5	AVG
MSP	8-8-77	22:12	27.3	28.0	30.3	28.5	26.0	25.5	20.5	21.3	47.5	70.0	0	20.5	0	73-75	72-74	73-75	72-74	72-74	73.4 (23.0)
"	"	22:48	26.9	28.0	30.3	27.6	25.2	24.5	19.6	20.3	47.0	68.5	0	19.5	0	71-73	71-73	71-73	71-73	70-72	71.8 (22.1)
"	"	23:24	27.3	28.0	27.7	27.0	24.5	23.7	19.7 20.0	20.6	42.0	69.0	0	19.5	0	71-73	71-73	70-72	70-72	71-73	71.6 (22.0)
"	"	24:00	27.3	28.2	24.5	26.4	24.0	23.0	20.4- 20.9	21.8	48.0	69.0	0	21.0	2-3	70-72	69-71	68-70	69-71	70-72	70.2 (21.2)
MSH	8-9-77	00:36	27.3	28.3	29.2	26.0	23.8	23.0	19.4	18.7	47.0	68.0	0	20.0	0	69-71	67-69	67-69	68-70	68-70	68.8 (20.4)
"	"	01:12	27.3	28.5	28.8	25.2	22.5	22.0	18.5	19.2	46.0	67.0	0	18.0	0	68-70	67-69	67-69	68-70	67-69	68.4 (20.2)
"	"	01:48	27.1	28.5	29.7	24.8	22.3	21.5	18.3	19.0	46.0	66.0	0	18.5	0	69-71	67-69	67-69	67-69	67-69	68.4 (20.2)
"	"	02:24	27.0	28.4	28.2	24.4	22.0	21.0	14.8 20.0	21.0 21.7	47.0	69.0	0	20.0	1-3	68-70	67-69	66-68	67-69	67-69	68.0 (20.0)
"	"	03:00	27.0	28.3	28.1	24.0	22.0	21.0	19.0	20.3 20.8	47.0	67.0	0	19.6	2-4	66-68	66-68	66-68	66-68	67-69	67.2 (19.6)
"	"	03:36	27.0	28.5	27.7	23.5	21.5	21.0	18.5	19.3	47.0	66.5	0	19.0	4-5	64-66	64-66	65-67	65-67	66-68	65.8 (18.8)
"	"	04:12	27.1	28.5	27.2	23.0	21.0	20.5	16.4	17.5	46.0	64.0	0	17.9	0	64-66	63-65	64-66	64-66	65-67	65.0 (18.3)
"	"	04:48	27.1	28.4	27.0	22.7	20.3	19.8	16.2	17.1	45.0	63.0	0	16.8	0	63-65	62-64	64-66	63-65	64-66	64.2 (17.9)
DAWN BEGINS																					
"	"	05:24	26.8	28.1	26.7	22.2	19.8	19.3	15.0	15.8	45.0	62.0	0	16.0	0	64-66	62-64	62-64	62-64	62-64	63.4 (17.4)
SUN RISING																					
"	"	06:00	27.2	28.3	26.7	22.2	19.7	19.0	16.3	17.1	45.0	62.5	0	16.5	0	62-64	62-64	58-60	61-63	58-60	61.2 (16.2)
SUN UP COMPLETELY - SENSORS NO LONGER SHADED																					
"	"	06:36	27.3	28.3	26.5	21.9	19.6	19.0	19.0	19.5	46.0	65.5	1	18.0	0	66-65	66-68	66-65	66-65	66-65	67.0 (19.4)
"	"	07:12	27.1	28.2	26.3	21.8	19.8 20.2	19.4	21.5	22.0	48.0	69.0	0	19.0	0	72-74	70-72	72-74	72-74	72-74	72.6 (22.6)

THERMAL DATA SHEET

MACARTHUR SITE-AIRPROBES IN SEWER PIPE
"MSP"
AUGUST 8-9, 1977

SITE	DATE	TIME	DEPTH OF PROBES °C #1 -31"	#2 -13"	#3 -7"	#4 -3"	#5 -2"	#6 1"	AIR #7 +2"	#8 +24"	°F WET	°F DRY	% CLOUD COVER	THERMOMETER +24"	WIND MPH	PRT °F (°C) 1	2	3	4	5	AVG.
MSP	8-9-77	07:48	27.3	28.3	26.2	22.0	21.7	22.0	29.4	24.8	49.0	71.0	0	22.0	0	76-78	76-78	76-78	80-82	78-80	78.2 (25.7)
"	"	08:24	27.4	28.5	26.2	22.7	22.7	23.5	26.4	24.5	49.0	69.5	0	21.5	0	80-82	86-88	84-86	82-84	84-86	84.2 (29.0)
"	"	09:00	27.7	28.5	26.2	23.7	24.5	26.0	29.6	27.8	51.0	74.0	2	24.0	0	91-93	88-90	92-94	90-92	90-92	91.2 (32.9)
"	"	09:36	27.[illegible]	28.5	26.2	25.0	26.1	28.2	29.5	30.3	52.0	75.0	0	25.0	0	97-99	97-99	100-102	98-100	97-99	98.8 (37.1)
"	"	10:12	28.1	28.6	26.4	26.1	28.0	31.2	32.5	30.8	52.0	77.0	0	26.0	0	102-104	100-102	104-106	102-106	106-108	103.8 (39.9)
"	"	10:48	28.[illegible]	28.7	26.6	27.4	29.5	33.0	34.5	31-32	53.0	79.0	10 E	28.0	4-6	108-110	>110	109-110	>110	>110	>110 (>43.3)
"	"	11:24	28.0	28.7	26.7	28.7	31.5	35.0	34.9	31.3-31.8	54.0	82.0	0 haze	29.0	2-3	>110	>110	>110	>110	>110	>110 (>43.3)
"	"	12:00	28.0	27.2	29.7	33.0	31.4	36.5	35.5	31.8-32.3	54.0	83.0	0 haze	30.0	5-6	>110	>110	>110	>110	>110	>110 (>43.3)
"	"	12:36	28.0	28.5	27.2	31.2	34.6	37.5	32.8	36.8	54.0	83.0	0	30.2	2-3	>110	>110	>110	>110	>110	>110 (>43.3)

MK & SV

THERMAL DATA SHEET

MACARTHUR SITE - SOIL PROBES IN HOLE "MSH"

AUGUST 8-9, 1977

UNIT #3 — DEPTH OF PROBES °C

SITE	DATE	TIME	#1 -48	#2 -31	#3 -16	#4 -8	#5 -4	#6 -2	#7 -1½	#8 -1	#9 -½	#10 -0	WET °F	DRY °F	% CLOUD COVER	SOLAMETER #2	WIND	PRT-4 °F 1	2	3	4	5	AVG.
MSH	8-8-77	12:15	24.8	27.0	27.2	25.6	28.0	33.6	37.0	42.6	45.4	50.7	54.0	81.0	0	—	3-4	—	—	—	—	—	—
"	"	12:36	24.8	27.0	27.2	26.1	28.9	34.9	38.2	43.6	46.3	751.0	53.0	80.0	0	—	2-3						
"	"	13:12	24.8	27.1	27.2	26.4	29.8 / 31.6	35.6	39.2 / 41.8	44.4	47.1	751.0	54.0	82.0	0	3.39	0-2						
"	"	13:48	24.8	27.1	27.1	27.0	32.5	36.7	40.4 / 42.8	45.4	48.0	751.0	55.0	84.0	0	3.36	0-2						
"	"	14:24	24.8	27.0	27.1	27.6	33.4	37.7	43.5	46.1	48.2	751.0	54.0	83.0	0	3.27	0-2						
"	"	15:00	24.8	27.0	27.0	28.0 / 30.1	34.1	38.2 / 41.0	43.9	46.4	48.5	751.0	53.0	82.0	0	3.03	0-2						
"	"	15:36	24.8	27.0	27.1	28.6	34.7	38.8	44.2	46.5	48.2	49.5	54.0	84.0	Some [illegible]	2.91	[illegible] 0-2						
"	"	16:12	24.8	27.0	27.1	29.1 / 31.0	35.2	39.0 / 41.6	43.9	45.6	46.7	48.2	55.0	85.0	0	2.39	3-4						
"	"	16:48	24.8	27.0	27.1	31.4	35.6	38.7 / 41.3	43.2	44.4	45.1	45.2	54.0	83.0	0	1.94	5-7						
"	"	17:24	measurement missed due to attempt to fix the PRT-4 by consulting with kai at dump																				
"	"	18:00	"		"		"		"		"	"											
"	"	18:25	24.8	27.0	27.3	32.2	35.6	37.0	37.5	37.4	36.8	35.0	53.5	83.5	0	0.61	2-3						
"	"	18:36	24.8	27.0	27.3	32.3	35.5	36.7	37.0	36.8	36.1	?	53.0	83.0	0	0.48	6-9						
SOIL PROBES SHADED BY 19:12																							
"	"	19:12	24.8	27.0	27.4	32.4	35.1	35.7	35.3	34.4	33.1	29.6 / 30.5	53.0	81.0	0	0.16	5-6						
SOLAMETER SHADED BY 19:2[illegible]																							
"	"	19:48	24.8	27.0	27.5	32.4	34.8	34.7	33.9	32.7	31.1 / 29.2	25.3	52.0	78.0	0	0.03	0						
"	"	20:24	24.8	27.0	27.6	32.3	34.1	33.4	32.1	28.7	26.7	23.1	51.0	71.0	0	0.01	0						

No PRT-4 measurements were obtained during the period from 12:15 to 20:24 because of trouble with the invertor. A different invertor was obtained from kai during the 18:00 measurement. Troubles with the second invertor were not solved until 20:24.

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THERMAL DATA SHEET

MAC ARTHUR SITE - SOIL PROBES IN HOLE
"MSH"
AUGUST 8-9, 1977

SITE	DATE	TIME	Unit #3 DEPTH OF PROBES °C #1 -46"	#2 -31"	#3 -16"	#4 -8"	#5 -4"	#6 -2"	#7 -1½"	#8 -1"	#9 -½"	#10 0"	°F WET	°F DRY	% CLOUD COVER	SOLAR METER	WIND	PRT °F (°C) 1	2	3	4	5	AVG.
MSH	8-8-77	21:00	24.8	27.0	27.7	30.7 32.4	33.4	32.3	28.8	27.0	25.2	21.4	49.0	73.0	0	0.01	0	74-76	74-76	74-76	75-77	74-76	75.2 (24.0)
"	"	21:36	24.8	27.0	27.8	30.8 32.3	32.7	29.2 31.2	27.3	25.5	23.8	20.3 20.7	48.5	70.5	0	0.01	0	72-74	74-76	74-76	74-76	74-76	74.6 (23.7)
"	"	22:12	24.8	26.9	27.8	30.3 31.9	30.4 32.0	28.4	26.5	24.7	23.0	19.6	47.5	70.0	0	0.01	0	72-74	72-74	72-74	72-74	73-75	73.2 (22.9)
"	"	22:48	24.8	26.9	27.9	30.0 31.8	29.5 31.4	27.4	25.5	23.8	22.1	18.8	47.0	68.5	0	0.012	0	72-74	72-74	70-72	72-74	72-74	72.6 (22.6)
"	"	23:24	24.8	26.9	28.0	29.8 31.5	29.0	26.7	24.8	23.1	21.5	18.2	42.0	69.0	0	0.012	0	68-70	70-72	70-72	71-73	71-73	71.0 (21.7)
"	"	24:00	24.8	26.9	28.1	29.4	28.5	26.2	24.3	22.6	21.1 21.3	19.3	48.0	69.0	0	0.012	2-3	68-70	70-72	70-72	69-71	68-70	70.0 (21.1)
"		00:36	24.8	26.8	28.1	29.1	27.8	25.6	23.8	22.3	20.4 21.8	17.8	47.0	68.0	0	0.013	0	66-68	68-70	68-70	68-70	68-70	68.6 (20.3)
"	8-9-77	01:12	24.8	26.8	28.2	28.8	27.5	25.1	23.3	21.6	19.8	16.9	46.0	67.0	0	0.019	0	66-68	68-70	68-70	68-70	68-70	68.6 (20.3)
"	"	01:48	24.8	26.9	28.5	28.2	26.8	24.4	22.6	20.6 21.0	19.2	16.5	46.0	66.0	0	0.021	0	65-67	68-70	67-69	67-69	68-70	68.0 (20.0)
"	"	02:24	24.8	26.9	28.2	28.2	26.5	24.1	22.4	20.7 20.8	19.2	16.6	47.0	69.0	0	0.021	1-3	67-69	68-70	67-69	68-70	67-69	68.4 (20.2)
"	"	03:00	24.8	26.9	28.2	28.0	26.1	23.8	22.2	20.4 20.8	19.2	17.1	47.0	67.0	0	0.021	2-4	66-68	66-68	66-68	68-70	68-70	67.8 (19.9)
"	"	03:36	24.8	26.9	28.1	27.6	25.8	23.5	21.9	20.2 20.6	19.0	16.9	47.0	66.5	0	0.022	4-5	64-66	66-68	66-68	66-68	67-69	66.8 (19.3)
"	"	04:12	24.8	26.8	28.1	27.4	25.4	23.2	21.6	19.8	18.4	16.0	46.0	64.0	0	0.025	0	62-64	62-64	63-65	64-66	64-66	64.0 (17.8)
"	"	04:48	24.8	26.8	28.0	27.1	25.0	22.7	20.6 20.9	19.0	17.6	15.1	45.0	63.0	0	0.025	0	62-64	64-66	63-65	63-65	64-66	64.2 (17.9)
	DAWN BEGINS																						
"	"	05:24	24.8	26.9	28.0	26.9	24.7	22.3	20.4	18.5	17.0	14.4	45.0	62.0	0	0.03	0	60-62	62-64	62-64	62-64	62-64	62.6 (17.0)
	SUN RISING																						
"	"	06:00	24.7	26.7	27.9	26.5	24.3	21.9	19.7	18.0	16.7	14.3	45.0	62.5	0	0.04	0	58-60	60-62	60-62	60-62	59-61	60.4 (15.8)
	SUN UP COMPLETELY																						
"	"	06:36	24.8	26.8	27.9	26.4	24.1	21.6	19.5	18.0	16.9	15.0	46.0	65.5	1%	0.22	0	65-67	65-67	64-66	64-66	66-6[illegible]	65.8 (19.0)

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-3-

THERMAL DATA SHEET

MACARTHUR SITE - SOIL PROBES IN HOLE "MSH"
AUGUST 8-9, 1977

SITE	DATE	TIME	DEPTH OF PROBES °C #1 -46"	#2 -31"	#3 -16"	#4 -8"	#5 -4"	#6 -2"	#7 -1½"	#8 -1"	#9 -½"	#10 -0"	WET	DRY	% CLOUD COVER	Solar-meter	WIND	PRT °F 1	2	3	4	5	[illegible]
MSH	8-9-77	07:12	24.8	26.8	27.8	26.1	23.7	21.4	19.6	18.4	17.8	18.1	48.0	69.0	0	0.467	0	72-74	70-72	70-72	76-78	72-74	73.0 (22.8)
"	"	07:48	24.8	26.8	27.8	25.9	23.5	21.7	20.5 20.8	20.2 20.8	20.5 20.6	23.3	49.0	71.0	0	0.925	0	80-82	78-80	78-80	76-78	80-82	79.4 (26.3)
"	"	08:24	24.8	26.8	27.7	25.7	23.6	22.4	22.3	22.7	23.6	27.5	49.0	69.5	0	1.36	0	86-88	84-86	87-89	82-84	80-82	84.8 (29.3)
"	"	09:00	24.8	26.9	27.7	25.7	23.8	23.6	24.2	25.4	27.0	34.6	51.0	74.0	2	1.87	0	92-94	95-97	92-94	88-90	90-92	92.4 (33.6)
"	"	09:36	24.8	26.8	27.6	25.4	24.4	25.2	26.7	28.7	30.8 32.6	37.8	52.0	75.0	0	2.33	0	102-104	98-100	100-102	102-104	98-100	101.0 (38.3)
"	"	10:12	24.8	26.8	27.5	25.4	25.1	26.8	29.0	33.1	35.4	44.6	52.0	77.0	0	2.69	0	108-110	106-108	>110	102-104	100-102	106.0 (41.1)
"	"	10:48	24.8	26.8	27.2	25.5	26.0	28.8	33.3	35.9	38.6	47.4	53.0	79.0	10% E	3.01	4-6	>110	>110	>110	>110	>110	>110 (>43.3)
"	"	11:24	24.8	26.8	27.3	25.8	27.0	32.2	35.0	37.9	43.0	49.0	54.0	82.0	0 haze S	3.19	2-3	>110	>110	>110	>110	>110	>110 (>43.3)
"	"	12:00	24.8	26.8	27.3	26.1	28.3	33.8	36.9	40.0 42.4	45.0	50.6	54.0	83.0	0 haze S	3.30	5-6	>110	>110	>110	>110	>110	>110 (>43.3)
"	"	12:36	24.7	26.8	27.2	26.5	29.2 31.1	35.0	38.4	43.9	46.7	51.0	54.0	83.0	0 haze	3.35	2-3	>110	>110	>110	>110	>110	>110 (>43.3)

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APPENDIX 2: CALIBRATION OF THE SOL-a-METERS

Table 2-1 shows readings taken from the two sol-a-meters at identical times in nearly identical conditions. The first set of columns show the results for meter #65407 which was calibrated by the manufacture in 1966 (Figure 2-1). The first column shows the voltage output of this sol-a-meter, used with an amplifier that increased the voltage 460 times. Column 2 lists the output in mV divided by the amplification. The next number across the row is the number of BTU/Hr/SqFt taken directly from line 1 in Figure 2-1. This value is then converted to cal/MW/cm^2 using the conversion factor shown. The last two columns for this unit are based on the line labeled 2 in Figure 2-1.

Readings for sol-a-meter #2102 are listed in the last three columns. The first of these columns shows the voltage output without an amplifier. Using Figure 2-2, this number is then converted to cal/min/cm^2. This number is comparable to the readings of the same units for sol-a-meter #65407. A quick comparison shows that line 1 in Figure 2-1 gives results more like that of Figure 2-2 than does line 2 in Figure 2-1. The last column in Table 2-1 shows the difference between the two values. Beneath this number is the percent error in terms of the 1966 values.

Figure 2-3 is a graph of the percent error as a function of the sol-a-meter #65407 readings based on Table 2-1 values. The graph serves as a way to correct the values of sol-a-meter 65407 in terms of the more recently calibrated sol-a-meter 2102.

Table 2-2 lists the original and corrected values from both sol-a-meters during the 24 hour collection period. The last column gives the converted chart value, the corrected value obtained using Figure 2-3. Figures 8 and 9 give these numbers plotted as a function of time.

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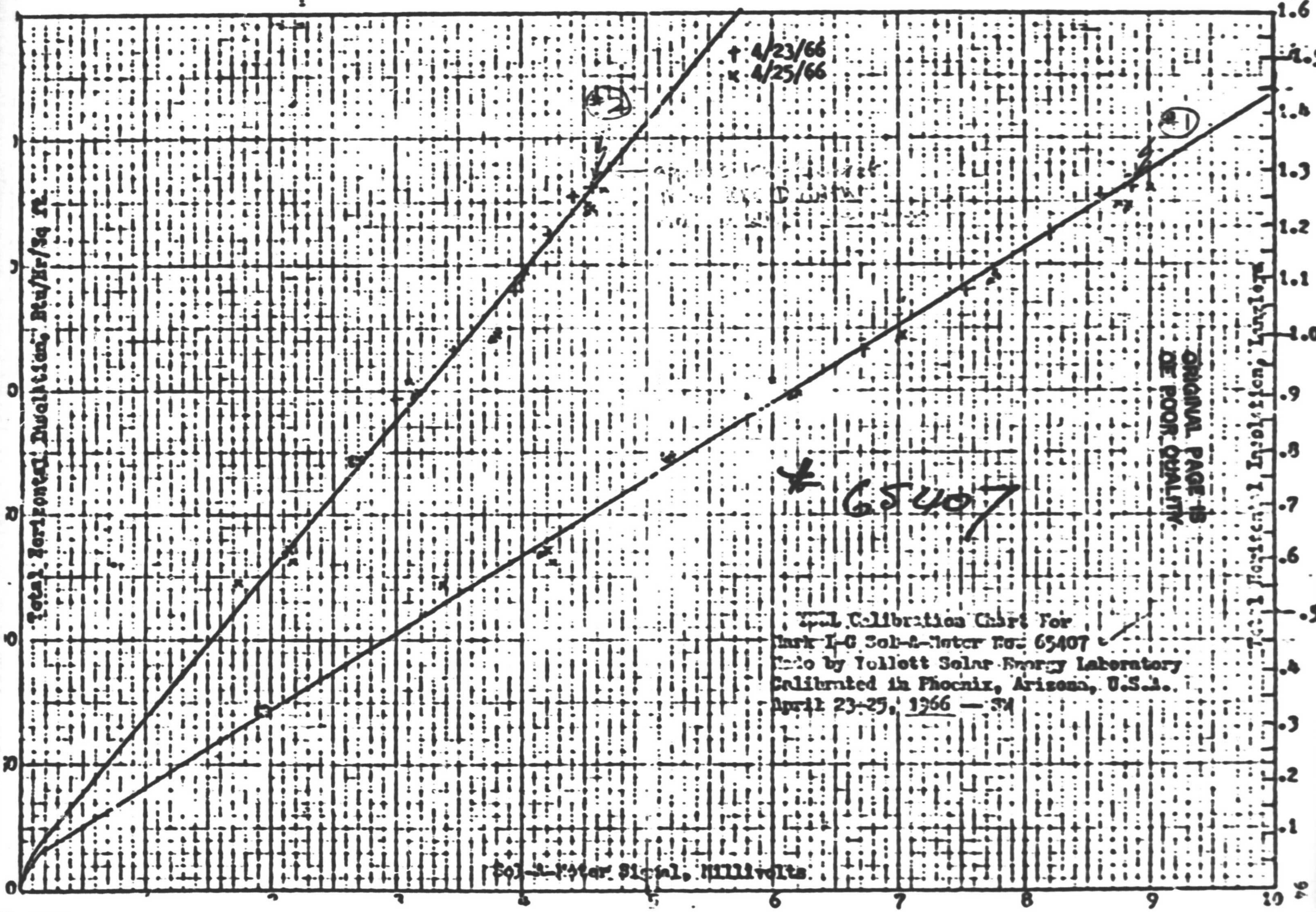
TABLE 2-1: Comparison of Two Sol-a-Meters

August 29, 1977 -- Clear - No Clouds

1966: Chart	#65407 × 460(Amps) Volts	#65407 / 460 mV	Chart Reading (1) BTU/Hr/SqFt	Reading (1) cal/min/cm^2	Chart Reading (2) BTU/Hr/SqFt	Reading (2) cal/min/cm^2	1972:	#2102 Reading mV	Chart Reading cal/min/cm^2	1966 - 1972 cal/min/cm^2 / % error 1966
	3.39	7.37	237	1.07	----	----		5.3	1.01	0.06 +6
	3.37	7.33	235	1.06	----	----		5.3	1.01	0.05 +5
	3.40	7.39	238	1.08	----	----		5.4	1.03	0.05 +5
	3.08	6.70	217	0.98	----	----		4.7	0.91	0.07 +7
	2.78	6.04	195	0.88	----	----		4.1	0.81	0.07 +8
	2.30	5.00	165	0.75	305	1.38		3.3	0.67	0.08 +11
	2.24	4.87	160	0.72	297	1.34		3.2	0.65	0.07 +10
	2.22	4.83	160	0.72	295	1.33		3.1	0.63	0.09 +13
	2.16	4.70	155	0.70	288	1.30		3.0	0.62	0.08 +11
	2.11	4.59	150	0.68	280	1.27		2.9	0.60	0.08 +12
	2.05	4.46	147	0.66	272	1.23		2.8	0.58	0.08 +12
	0.84	1.83	67	0.30	118	0.53		0.7	0.23	0.07 +23
	0.82	1.78	65	0.29	114	0.52		0.7	0.23	0.06 +21
*	0.53	1.15	46	0.21	77	0.35		0.7	0.23	-0.02 -10
	Anomalous point due to shading of 1966 sol-a-meter. Not used in calibration.									
	0.51	1.11	45	0.20	75	0.34		0.3	0.16	0.04 +20
	0.51	1.11	45	0.20	75	0.34		0.3	0.16	0.04 +20
	0.50	1.09	44	0.20	73	0.33		0.3	0.16	0.04 +20
	0.49	1.07	43	0.19	72	0.33		0.3	0.16	0.03 +16
	0.48	1.04	42	0.19	71	0.32		0.2	0.14	0.05 +26
	0.48	1.04	42	0.19	71	0.32		0.2	0.14	0.05 +26
	0.35	0.76	37	0.17	54	0.24		0.1	0.12	0.05 +29
	0.32	0.70	31	0.14	50	0.23		0.1	0.12	0.02 +14
	0.32	0.70	31	0.14	50	0.23		0.0	0.10	0.04 +29
						Less accurate in all cases here than in the other				$\bar{x}$ = 0.05

FIGURE 24 CALIBRATION-VIS



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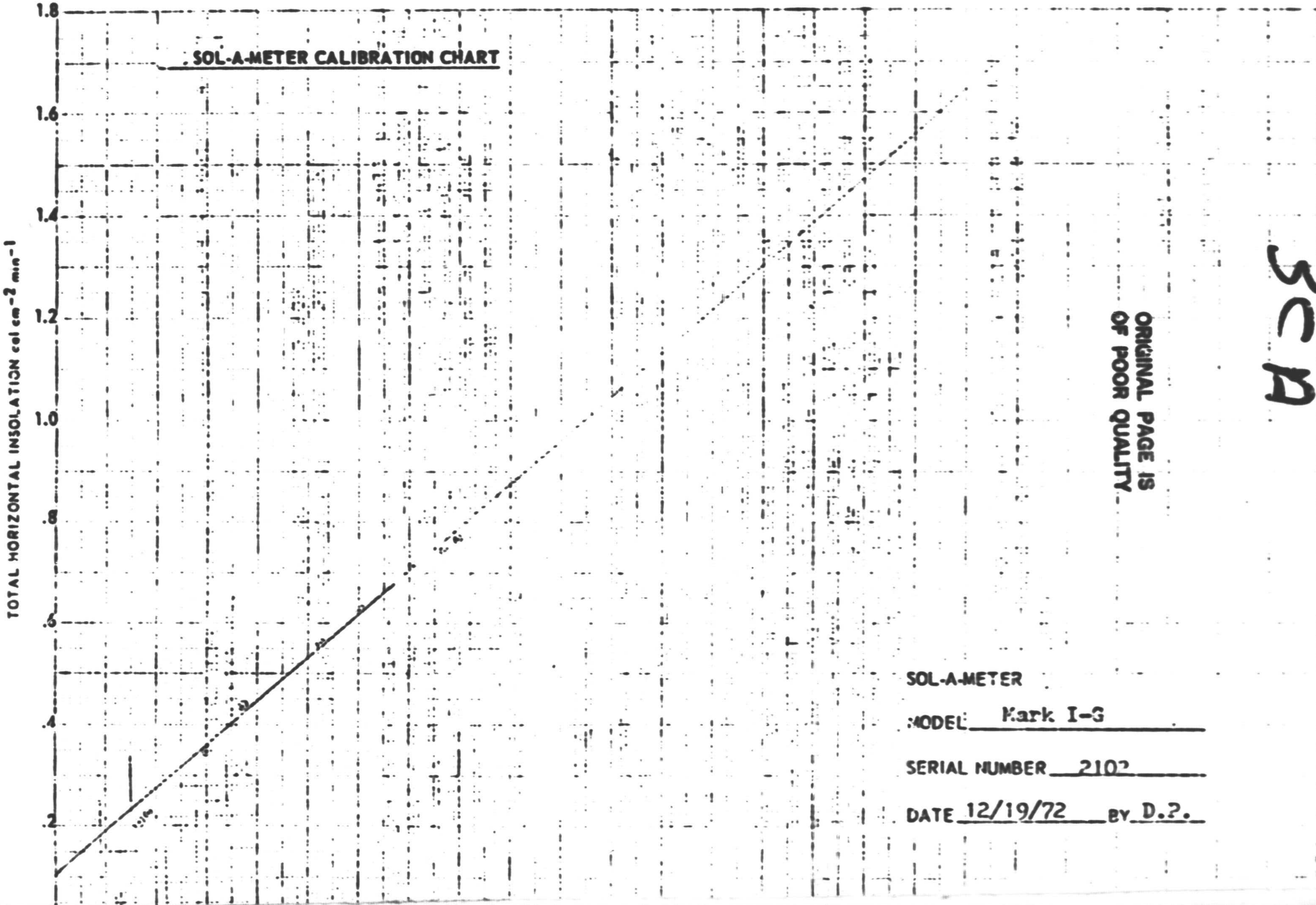
MATRIX, INC.

MESA,

FIGURE 22



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C-2

COMPARISON OF TWO SCI-A-METERS,
19?? AND 1972 CALIBRATIONS

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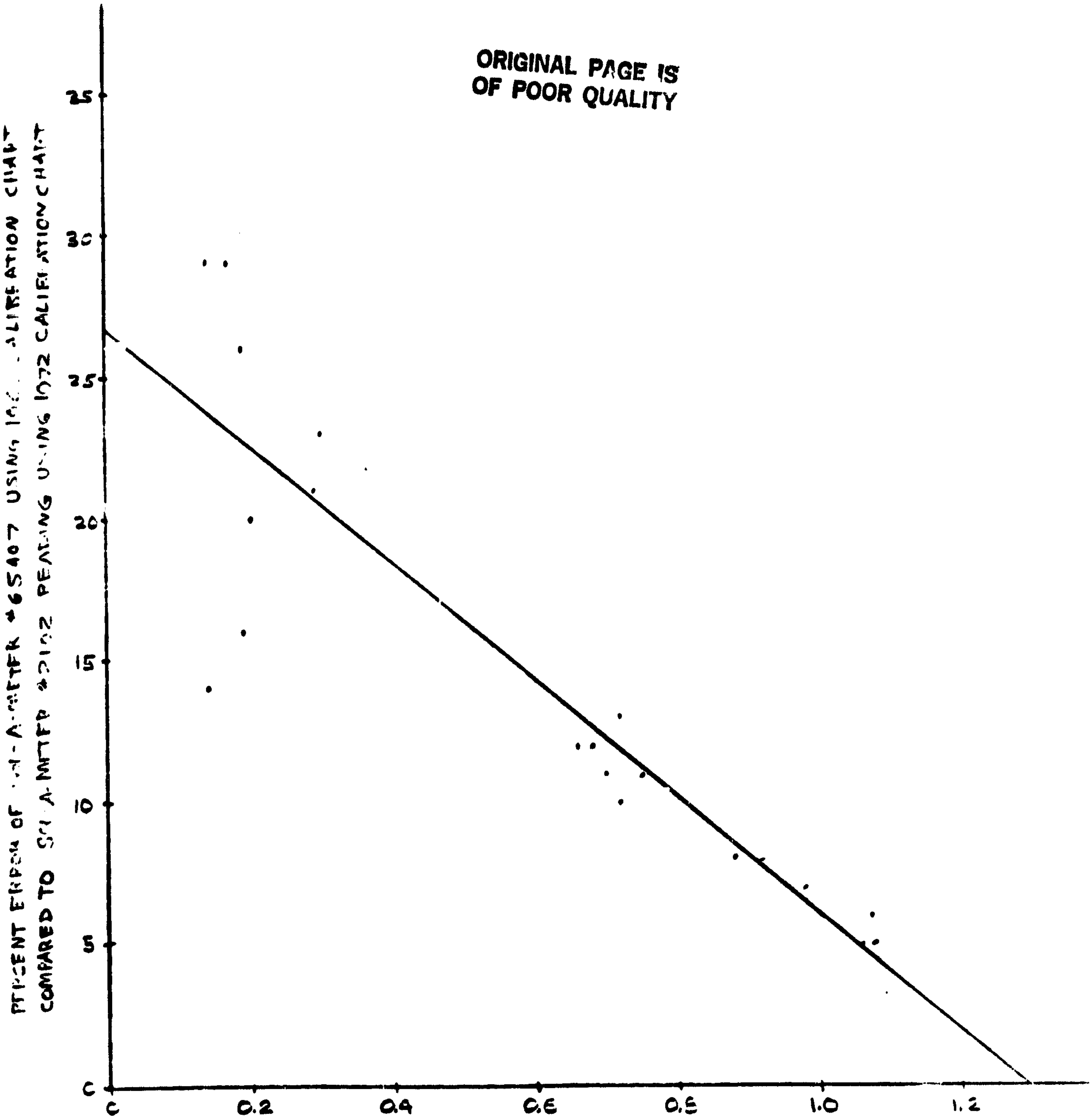

TABLE 2-2: Sol-A-Meter Readings and Values

Nevada Sites, August 8-9, 1977

	MacArthur Site, #2101, 1972, Amp #2 (=460)				Anaconda Site, #65407, 1966, Amp #3 (=460)				
	Time of Reading	Reading Value (Volts)	Reading Value ÷ 460(mV)	Chart Value (cal/min/cm²)	Time of Reading	Reading Value (Volts)	Reading Value ÷ 460(mV)	Chart Value #1 (BTU/Hr/SqFt)	Chart Value (cal/min/cm²)
8/8/77	12:15	----	----	----	12:07	4.32	9.39	300 (RV) Revised Value:	1.36 1.36
	12:36	----	----	----	12:36	4.41	9.59	305 RV	1.38 1.38
	13:12	3.39	7.37	1.37	13:12	4.51	9.80	312 RV	1.41 1.41
	13:48	3.36	7.30	1.35	13:48	4.42	9.61	305 RV	1.38 1.38
	14:24	3.27	7.11	1.32	14:24	4.30	9.35	297 RV	1.34 1.34
	15:00	3.03	6.59	1.23	15:00	3.90	8.48	276 RV	1.25 1.25
	15:36	2.81	6.11	1.15	15:36	3.66	7.96	255 RV	1.15 1.10
	16:12	2.39	5.20	1.00	16:12	3.12	6.78	218 RV	0.99 0.93
	16:48	1.94	4.22	0.83	16:48	2.57	5.59	183 RV	0.83 0.76
	17:24	----	----	----	17:24	2.04	4.43	147 RV	0.66 0.57
	18:00	----	----	----	18:00	1.44	3.13	107 RV	0.48 0.40
	18:25	0.61	1.33	0.33	---	----	----	----	----
	18:36	0.48	1.04	0.28	18:36	0.93	2.02	73 RV	0.33 0.77
	19:17 Shaded	0.16	0.35	0.16	19:12 Shaded	0.43	0.93	40 RV	0.18 0.14
	19:48	0.03	0.07	0.12	19:48	0.16	0.35	20 RV	0.09 0.07
	20:24	0.01	0.02	0.10	20:24 Dark	0.08	0.17	15 RV	0.07 0.05
	21:00	0.01	0.02	0.10	21:00	0.06	0.13	12 RV	0.05 0.04
	21:36	0.01	0.02	0.10	21:36	----	----	----	----
	22:12	0.01	0.02	0.10	22:12	----	----	----	----
	22:48	0.01	0.02	0.10	22:48	----	----	----	----
	23:24	0.01	0.02	0.10	23:24	----	----	----	----
	24:00	0.01	0.02	0.10	24:00	----	----	----	----
8/9/77	00:36	0.01	0.02	0.10	00:36	----	----	----	----
	01:12	0.02	0.04	0.11	01:12	----	----	----	----
	01:48	0.02	0.04	0.11	01:48	----	----	----	----
	02:24	0.02	0.04	0.11	02:24	----	----	----	----
	03:00	0.02	0.04	0.11	03:00	----	----	----	----
	03:36	0.02	0.04	0.11	03:36	----	----	----	----
	04:12	0.03	0.07	0.12	04:12	----	----	----	----
	04:48 Dawn	0.03	0.07	0.12	04:48	----	----	----	----
	05:24 Sunrise	0.03	0.07	0.12	05:24	----	----	----	----
	06:00 Sun up	0.04	0.09	0.12	06:00	0.05	0.11	11 RV	0.05 0.04
	06:36	0.22	0.48	0.19	06:36	----	----	----	----
	07:12	0.47	1.02	0.27	07:12	0.62	1.35	52 RV	0.24 0.19
	07:48	0.93	2.02	0.45	07:48	1.10	2.39	84 RV	0.38 0.31
	08:24	1.36	2.96	0.61	08:24	1.63	3.54	120 RV	0.54 0.46
	09:00	1.87	4.04	0.80	09:00	2.28	4.96	163 RV	0.74 0.65
	09:36	2.33	5.07	0.98	09:36	2.78	6.04	197 RV	0.89 0.81
	10:12	2.69	5.85	1.11	10:12	3.18	6.91	224 RV	1.01 0.95
	10:48	3.01	6.54	1.23	10:48	3.64	7.91	[illegible] RV	1.15 1.17
	11:24	3.19	6.93	1.30	11:24	3.9?	8.39	275 RV	1.24 1.2?

1966 -- lower values for indicated voltages

APPENDIX 3: RECORDING THERMOMETERS

Table 3-1 shows the readings for both recording thermometers A and B under nearly identical conditions. These readings are compared to those of the new 5810 thermometer unit. Asterisks indicate instances where the needle of recording thermometer A became stuck at higher temperatures. Averages of all of these comparisons are also listed in this table.

It is important to note that the probes were improperly set in the field. The whole probe and several inches of the wire should have been submerged into the water because of the conductive metal wire connected to the probe. Instead, only the probe was in the water. As a result, the recorded water temperatures appear too variable due to the greater temperature change in the air. Due to this error, this attempt to calibrate the recorded data may not be very meaningful.

Figure 3-1 is a plot of the temperature recorded by thermometers A and B as a function of the temperature given by the 5810 unit. Lines were visually fitted to the points. Note that the two circled points represent values found in the field. Equations of these lines were then calculated for both thermometers.

Figure 3-2 is simply a graph of temperature readings from thermometers A versus B. The points represent values recorded for both thermometers in the same water bath.

Table 3-2, 3-3, and 3-4 are the temperature recording charts made at Anaconda's leach pond.

Table 3-5 lists the temperature values for both the thermometers every 30 minutes. The correction factors are from Figure 3-1. The corrected

temperatures are also listed for each original value of A and B. Figures 11 and 12 show these values plotted as a function of time. The bottom of Table 3-5 lists the temperature range of both stations. The first calculation is based upon raw data from the recording chart, the second set is based on the correction terms used in this report. The final listing uses the calibration factor determined in the field (circled points in Figure 3-1).

TABLE 3-1: Calibration of Recording Thermometers

Date	A - B °C	Thermometer A °C	Thermometer B °C	Reading °C	5810-1-A °C	5810-1-B °C	Description and Comments
8/6/77	----	30.0	----	22.5	-7.5	----	Anaconda 'lake', Nevada
	----	----	26.8	22.7	----	-4.1	" " "
8/25/77	3.3	22.5	19.2	----	----	----	Air temperature in office A-12
8/26/77	3.0	22.0	19.0	----	----	----	Air temperature in lab A-16
	----	----	35.0	36.5	----	+1.5	Water in lab A-16.
	----	37.5	----	36.0	-1.5	----	None of the cord above the
	----	----	32.8	34.0	----	+1.2	sensing probe was submerged
	----	35.0	----	33.5	-1.5	----	into the water, so the con-
	----	----	30.2	31.4	----	+1.2	conductivity of the wire should
	----	32.0	----	30.8	-1.2	----	dampen the readings towards
	----	----	27.0	28.0	----	+1.0	ambient which was about 20°C.
	----	29.0	----	27.5	-1.5	----	The same was done in the field,
	----	----	21.0	21.0	----	0	but with unknown air tempera-
	----	24.5	----	21.0	-3.5	----	tures.
8/29/77	2.0	21.0	19.0	19.4	-1.6	+0.4	All of the following are also done in a
	4.0	34.0	30.0	31.0	-3.0	+1.0	water bath as above except ~ 2" of
	5.5	34.0	28.5	29.3	-4.7	+0.8	cord is submerged into water.
	5.0	49.5	44.5	51.0	+1.5	+6.5	
	*9.0	44.0	35.0	36.0	-8.0	+1.0	Needle on A is stuck on high T.
	4.0	39.0	35.0	36.0	-3.0	+1.0	Needle on A is not stuck.
	*8.0	37.0	29.0	29.0	-8.0	0.0	Needle on A is stuck.
	3.0	32.0	29.0	29.0	-3.0	0.0	Needle on A is not stuck.
	*5.5	26.0	20.5	30.0	+4.0	+9.5	Needle on A is stuck.
	2.5	23.0	20.5	30.0	+7.0	+9.5	Needle on A is not stuck.
	*4.0	20.0	16.0	14.5	-5.5	-1.5	Needle on A is stuck.
	1.0	17.0	16.0	14.5	-2.5	-1.5	Needle on A is not stuck.
	2.0	19.8	17.8	17.6	-2.2	-0.2	

*Not used in averages since refers to temperature when needle is not working properly; when stuck at a high temperature. Also, left off following graphs.

$\overline{A - B} = 3.2$

$\overline{5810\text{-}1\text{-}A} = -1.48$

$\overline{5810\text{-}1\text{-}B} = +1.77$

Using graph of A and B vs 5810-1: Temp. A = temp 5810 + 2°C or Temp = Temp A - 2°C

Temp B = .92 temp 5810 + 1.74°C or $\text{temp} = \dfrac{\text{Temp B} - 1.74°C}{.92}$

BUT, the air temperature around the conducting metal wire to the probe will have an effect on the temperature recorded. So, night temperatures will be too cold and day temperatures too hot. This factor is not accounted for in the given temperatures of the Anaconda "lake".

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TABLE 3-5: Recording Thermometer Readings
August 7-9, 1977

Date	Time	Recorded Temp. For A °C	Correction Factor	Corrected Temp For A °C	Recorded Temp. For B °C	Correction Factor	Corrected Temp For B °C	Difference A-B °C
8/7/77	12.00	31.0	"A"-2.0°C	29.0	26.5	"B"-1.74°C / 0.92	26.9	2.1
	12:30	31.0		29.0	27.0		27.5	2.5
	13:00	31.5		29.5	27.5		28.0	1.5
	13:30	31.5		29.5	27.8		28.3	1.2
	14:00	31.8		29.8	28.0		28.5	1.3
	14:30	31.8		29.6	26.0		28.5	1.3
	15:00	31.8		29.8	28.2		28.8	1.0
	15:30	31.3		29.3	28.0		28.5	0.8
	16:00	31.2		29.2	27.2		27.7	1.5
	16:30	31.2		29.2	27.0		27.5	1.7
	17:00	31.1		29.1	27.0		27.5	1.6
	17:30	31.2		29.2	26.8		27.2	2.0
	18:00	31.2		29.2	26.5		26.2	2.3
	18:30	31.2		29.2	26.0		26.4	2.8
	19:00	31.0		29.0	25.7		26.0	3.0
	19:30	30.5		28.5	25.4		25.7	2.8
	20:00	30.0		28.0	25.2		25.5	2.5
	20:30	29.9		27.9	25.0		25.3	2.6
	21:00	29.7		27.7	24.9		25.2	2.5
	21:30	29.0		27.0	24.7		25.0	2.0
	22:00	28.1		26.1	24.5		24.7	1.4
	22:30	28.1		26.1	24.2		24.4	1.7
	23:00	28.0		26.0	24.0		24.2	1.8
	23:30	27.8		25.8	23.8		24.0	1.8
	24:00	27.7		25.7	23.5		23.7	2.0
8/8/77	24:30	27.5		25.5	23.3		23.4	2.1
	01:00	27.3		25.3	23.1		23.2	2.1
	01:30	27.1		25.1	23.0		23.1	2.0
	02:00	27.0		25.0	23.0		23.1	1.9
	02:30	27.0		25.0	22.8		24.8	0.2
	03:00	26.5		24.5	22.5		22.6	1.9
	03:30	26.2		24.2	22.2		22.4	1.8
	04:00	26.2		24.2	22.1		22.[illegible]	2.1
	04:30	26.2		24.2	22.0		22.0	2.2
	05:00	26.1		24.1	22.2		22.2	1.9
	05:30	26.0		24.0	22.0		22.0	2.0
	06:00	26.0		24.0	21.8		21.8	2.2
	06:30	26.0		24.0	21.5		21.5	2.5
	07:00	26.0		24.0	22.0		22.0	2.0
	07:30	26.0		24.0	23.0		23.1	0.9
	08:00	26.0		24.0	23.1		23.2	0.8
	08:30	26.5		24.5	23.5		23.7	0.8
	09:00	28.0		26.0	24.5		24.7	1.3
	09:30	28.5		26.5	25.5		25.8	0.7
	10:00	29.0		27.0	25.8		26.2	0.8
	10:30	30.0		28.0	26.0		26.4	1.6
	11:00	30.5		28.5	26.2		26.6	1.9
	11:30	31.0		29.0	26.7		27.1	1.9
	12:00	31.5		29.5	26.7		27.1	2.4
	12:30	31.8		29.8	27.0		27.5	2.3
	13:00	31.8		29.8	27.5		28.0	1.8
	13:30	32.0		30.0	27.5		28.0	2.0
	14:00	33.0		31.0	28.0		28.5	2.5
	14:30	33.0		31.0	29.0		29.6	1.4

Recording Thermometer Readings: 8/8 – 8/9/77

Date	Time	Recorded Temp. For A °C	Correction Factor	Corrected Temp. For A °C	Recorded Temp. For B °C	Correction Factor	Corrected Temp. For B °C	Difference A-B °C
8/8/77	15:00	33.0	"A"-2.0°C	31.0	29.2	$\frac{\text{"B"}-1.74°C}{0.92}$	29.9	1.1
	15:30	33.0		31.0	29.0		29.6	1.4
	16:00	32.8		30.8	29.0		29.6	1.2
	16:30	32.7		30.7	28.5		29.1	1.6
	17:00	32.5		30.5	27.0		27.5	3.0
	17:30	32.2		30.2	26.8		27.2	3.0
	18:00	31.8		29.8	26.8		27.2	2.6
	18:30	31.3		29.3	26.3		26.7	2.6
	19:00	30.8		28.8	25.9		26.3	2.5
	19:30	30.2		28.2	25.9		26.3	1.9
	20:00	30.0		28.0	25.5		25.8	2.2
	20:30	29.6		27.6	25.0		25.3	2.3
	21:00	29.0		27.0	25.0		25.3	1.7
	21:30	29.2		27.2	24.8		25.1	2.1
	22:00	29.0		27.0	24.4		24.6	2.4
	22:30	29.0		27.0	24.2		24.4	2.6
	23:00	29.0		27.0	24.1		24.3	2.7
	23:30	29.0		27.0	24.0		24.2	2.8
	24:00	28.5		26.5	24.0		24.2	2.3
8/9/77	24:30	28.0		26.0	24.0		24.2	1.8
	01:00	28.0		26.0	24.0		24.2	1.8
	01:30	27.8		25.8	23.3		23.4	2.4
	02:00	27.5		25.5	23.2		23.3	2.2
	02:30	27.2		25.2	23.2		23.3	1.9
	03:00	27.2		25.2	23.1		23.2	2.0
	03:30	27.2		25.2	23.0		23.1	2.1
	04:00	27.0		25.2	23.0		23.1	2.1
	04:30	26.8		24.8	22.5		22.6	2.2
	05:00	26.8		24.8	22.5		22.6	2.2
	05:30	26.6		24.6	22.2		22.4	2.2
	06:00	26.5		24.5	22.2		22.4	2.1
	06:30	26.5		24.5	22.2		22.4	2.1
	07:00	26.8		24.8	23.0		23.1	1.7
	07:30	27.0		25.0	23.8		24.0	1.0
	08:00	27.8		25.8	24.0		24.2	1.6
	08:30	29.0		27.0	25.5		25.8	1.2
	09:00	30.0		28.0	26.0		26.4	1.6
	09:30	30.8		28.8	26.2		26.6	2.2
	10:00	31.2		29.2	26.8		27.2	2.0
	10:30	31.8		29.8	27.0		27.5	2.3
	11:00	32.0		30.0	28.0		28.5	1.5
	11:30	32.5		30.5	27.8		28.3	2.2
	12:00	32.8		30.8	27.5		28.0	2.8
	12:30	33.0		31.0	28.0		28.5	2.5

(1) Max Recorded A: 33.0
Min Recorded A: 26.0 Δ 7 C

(2) Max Corrected A: 31.0
Min Corrected A: 24.0 Δ 7 C

(3) Max Field Corrected A: 33.0-7.5 = 25.5
Min Field Corrected A: Δ 7 C

(4) Max Recorded B: 29.2
Min Recorded B: 21.5 Δ 7.7°C

(5) Max Corrected B: 29.9
Min Corrected B: 21.5 Δ 8.4°C

(6) Max Field Corrected = 29.2-4.1 = 25.1
Min Field Corrected = 21.5-4.1 = 17.4

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CALIBRATION OF RECORDING THERMOMETERS 8/77

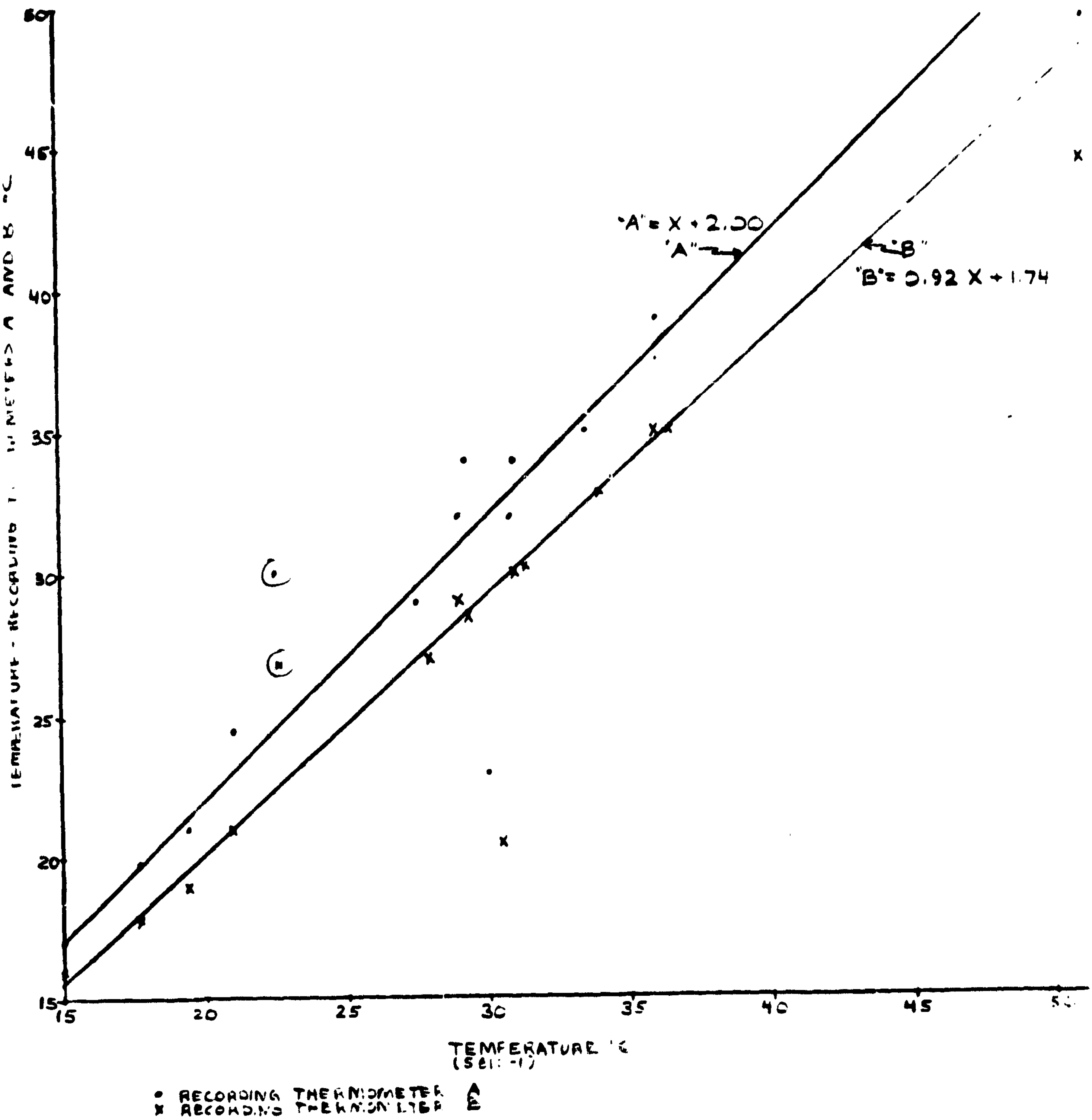


FIGURE 17

CALIBRATION OF RECORDING THERMOMETERS

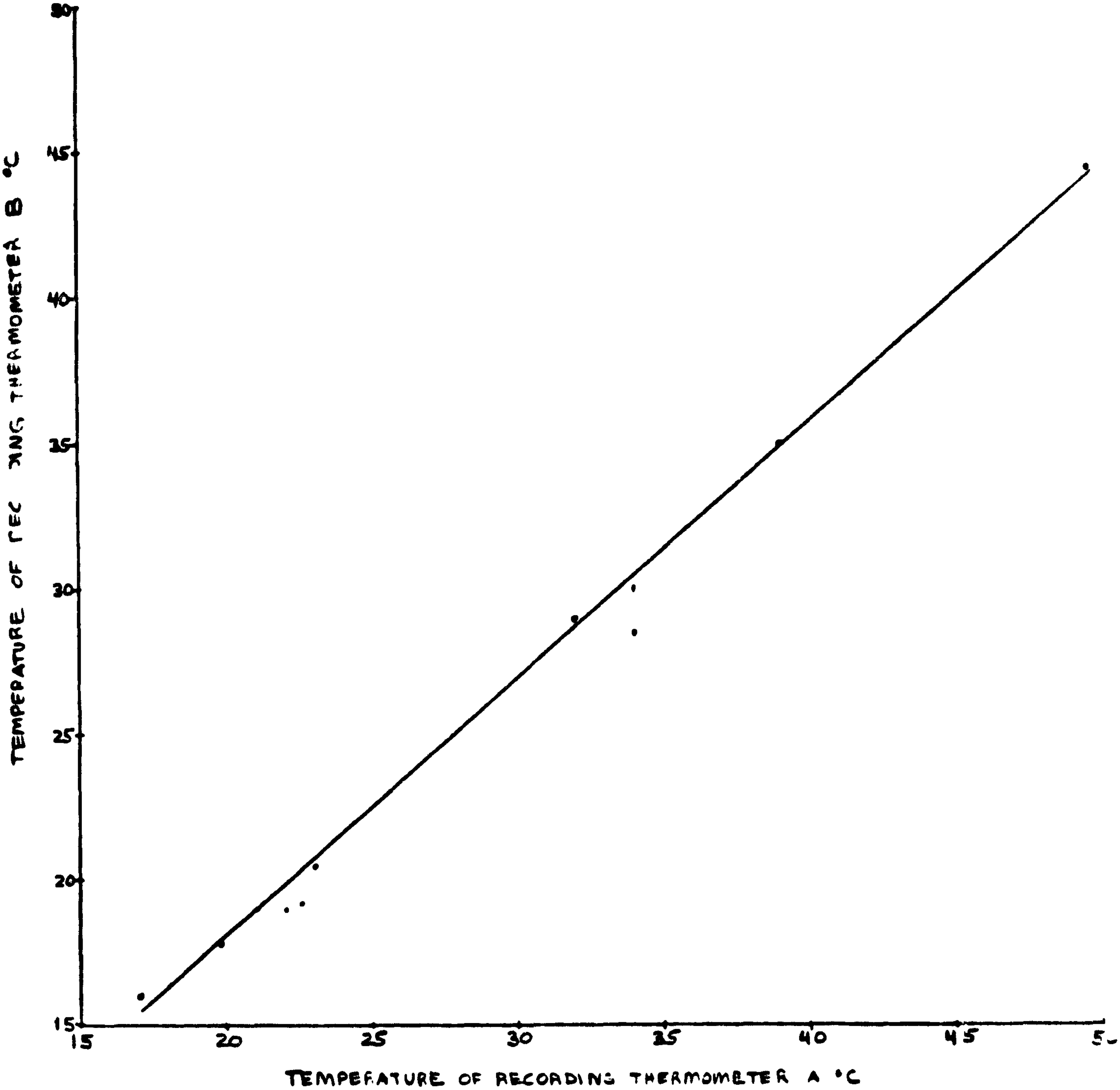
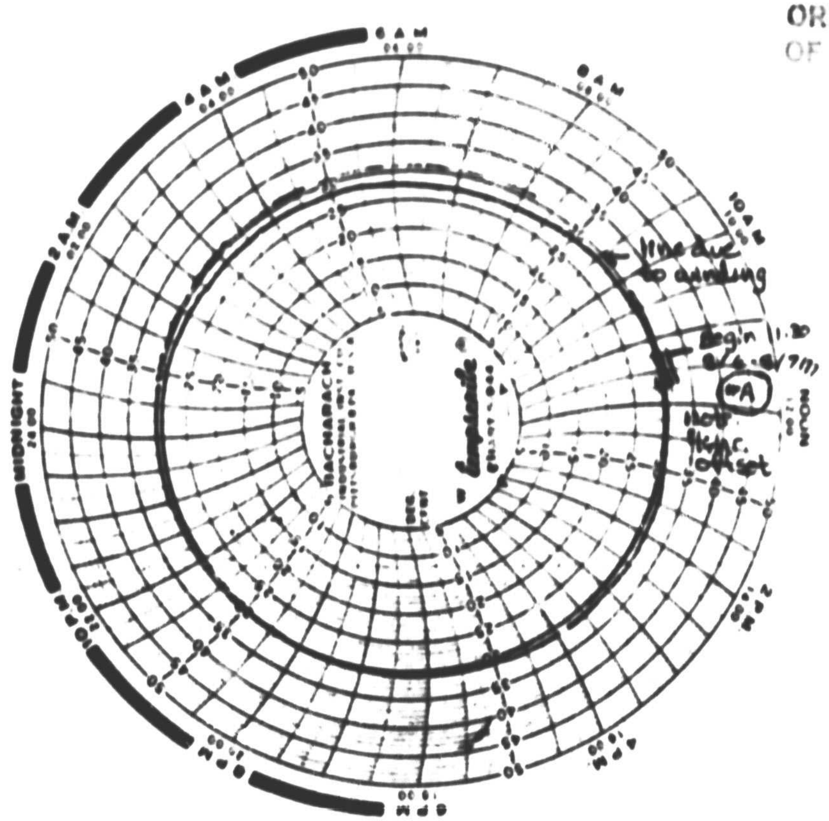


FIGURE 18

RECORDING THERMOMETER RESULTS 8/6/77 - 8/7/77
ANACONDA "LAKE"



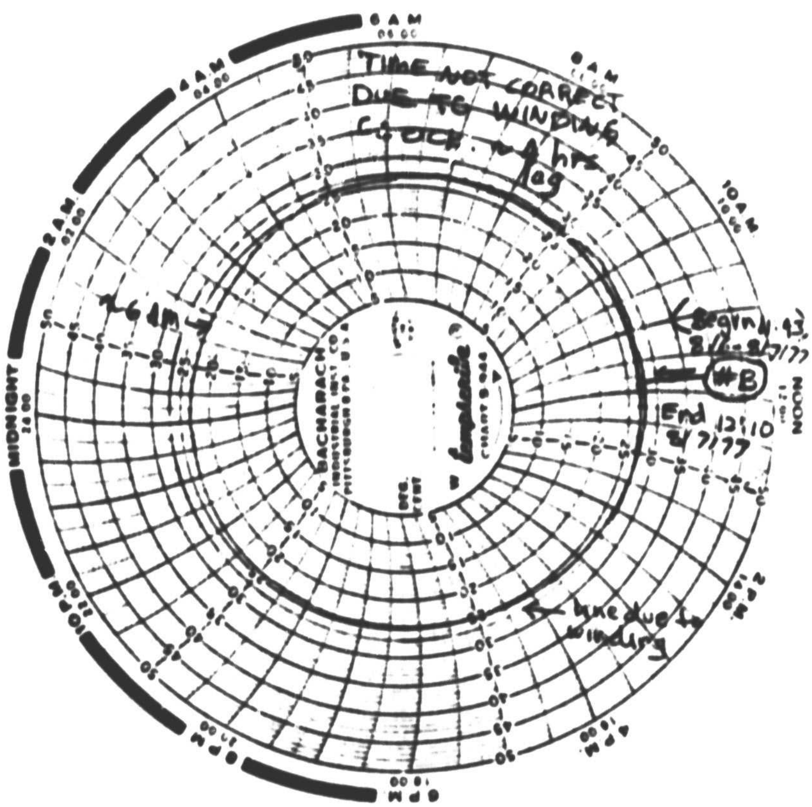
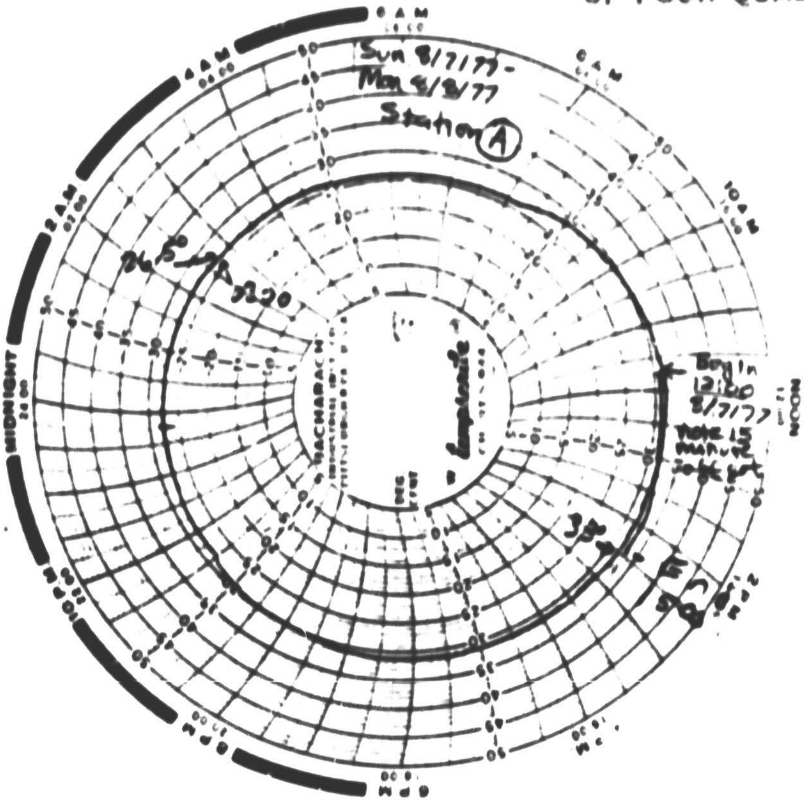


TABLE 6

RECORDING THERMOMETER RESULTS 8/7/77-8/8/77
ANACONDA LAKE



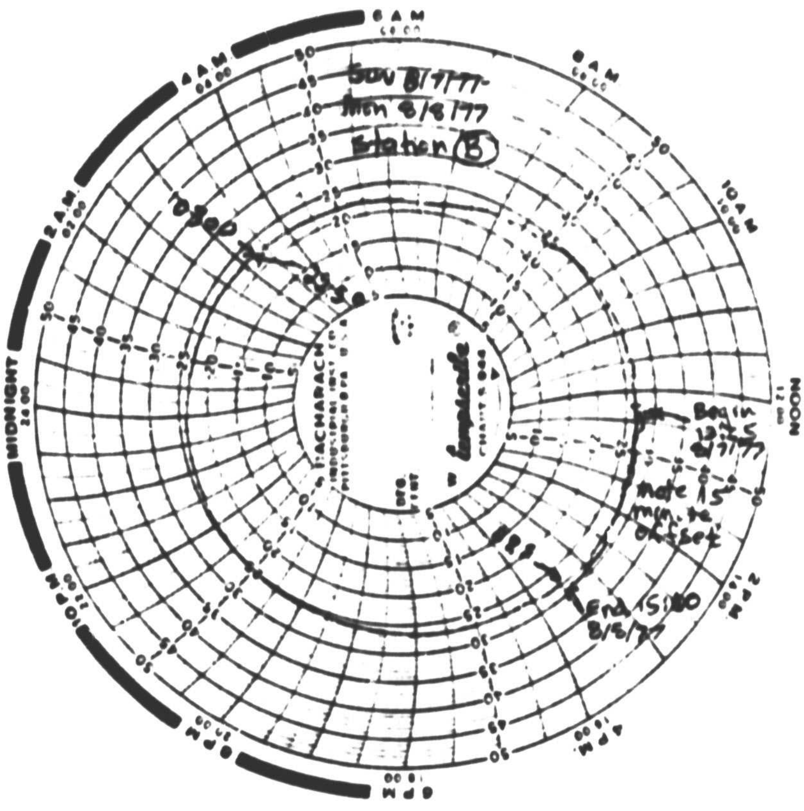
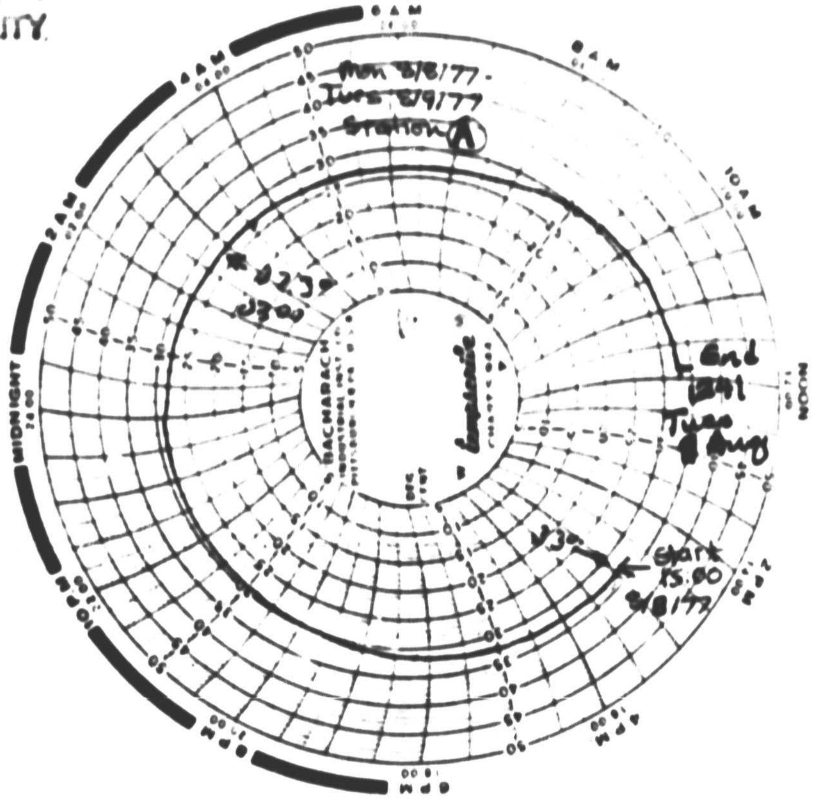


TABLE 7

RECORDING THERMOMETER RESULTS 8/8/77-

ANACONDA LAKE



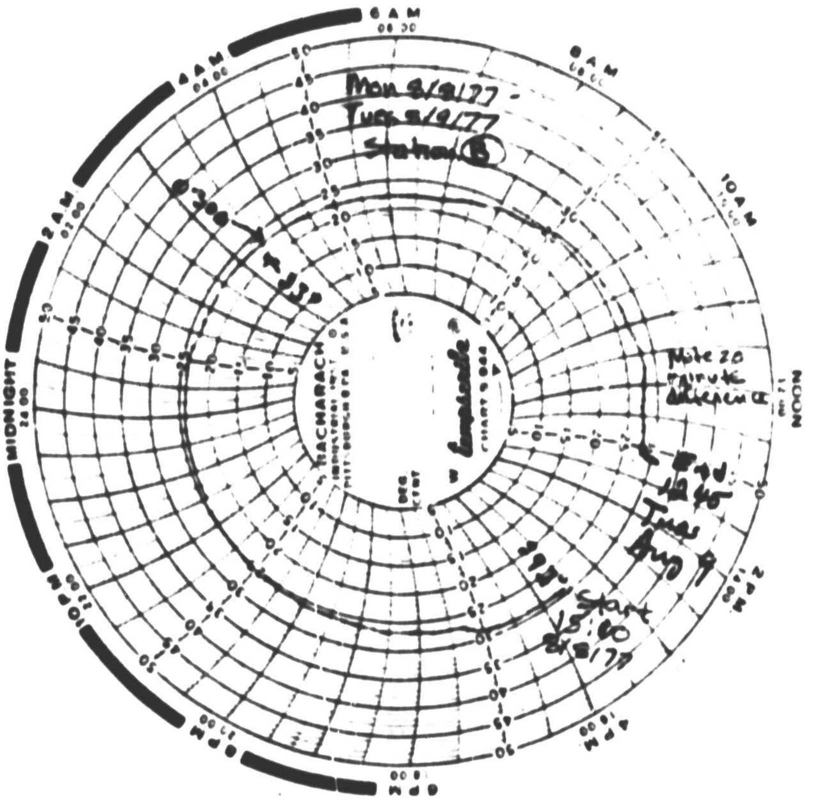


TABLE 9

APPENDIX 4: SOIL SAMPLES

Table 4-1 lists the wet and dry weights of each soil sample, and the percent of moisture by weight. Each sample is labeled by station (Anaconda or MacArthur) and by depth below the surface. Asterisks indicate those samples which were determined to be too small to be employed. Plate 5 shows samples after the drying process.

Samples were collected at two different times. One set was obtained August 5, 1977 while the hole was being dug out. The soil in the auger was deposited into a plastic air tight sample bottle. Additional samples were collected August 9, 1977 after thermal measurements were completed. These samples were obtained while dismantling the stations.

Each sample was weighed before and after being dried in an oven. Samples were removed from the sample bottles and placed on previously weighed watch-glasses. Unfortunately, the very dry soils were gaining weight very quickly during the time taken to weigh the samples. Thousandths of a gram change were readily discernible for both dry samples gaining weight, and moister soils losing weight. In each case, those which were losing weight had a higher water content than those which were gaining weight. No weight change was noticed for the smaller samples collected August 9, 1977 from the MacArthur sewer pipe. The wetter samples were re-weighed after airdrying for 45 minutes. Changes of over 0.1 gram were observed.

Each sample was very carefully placed into a drying oven, made by the National Appliance Company. The oven was set at approximately 4.5 which corresponds to a temperature range of 112 - 120°C. All samples were allowed to dry over 24 hours. To ascertain the dryness of the soil, one can weigh

the samples periodically during the drying period until no discernible change in weight is observed. Warmer temperatures and more time can always result in a drier soil, if only by breaking down some of the clay minerals in the soil.

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TABLE 4-1: Moisture Content of Nevada "Thermal Test" Soils Collected August 5 - 9, 1977

Sample Name	Date Collected	Watchglass Weight g	Watchglass & Sample Weight g	'Wet' Sample Weight g	Number Hours In Oven	Temperature of Oven °C	Watchglass & Sample Weight g	'Dry' Sample Weight g	Weight of Moisture g	% Moisture
Dump 0-1" Sewer Pipe	8/5/77	24.1	144.6	120.5	54	110-120	143.3	119.2	1.3	1.0
Dump - 4½" Sewer Pipe	8/5/77	24.9	92.4	67.5	54	110-120	90.4	65.5	2.0	2.9
Dump - 27" Sewer Pipe	8/5/77	24.1	154.7	130.1	63-3/4	110-120	148.6	124.5	5.6	4.3
Dump - 31" Sewer Pipe	8/5/77	25.9	150.8	124.9	63-3/4	110-120	144.8	118.9	6.0	4.8
Dump 0-3" Spike	8/5/77	31.0	150.8	119.8	63-3/4	110-120	147.6	116.6	3.2	2.7
Dump - 16" Spike	8/5/77	27.4	143.8	116.4	63-3/4	110-120	136.8	109.4	7.0	6.0
Mac 1 - 0" Soil Probes	8/9/77	23.9	146.3	122.4	54	110-120	146.1	122.2	0.2	0.1
Mac 1 - ½" Soil Probes	8/9/77	24.5	97.2	73.2	54	110-120	97.3	72.8	0.4	0.5
Mac 1 - 1" Soil Probes	8/9/77	27.4	78.7	51.3	54	110-120	78.4	51.0	0.3	0.6
Mac 1 - 2" Soil Probes	8/9/77	27.6	90.7	63.0	54	110-120	90.0	62.4	0.7	1.1
Mac 1 - 8" Soil Probes	8/9/77	31.0	146.6	115.6	54	110-120	145.3	114.3	1.3	1.1
Mac 1 0-1" Sewer Pipe	8/5/77	21.9	145.6	124.0	54	110-120	145.2	123.3	0.6	0.5
Mac 1* - 1½" Sewer Pipe	8/9/77	17.5	18.5	1.0	54	110-120	18.5	*1.0	0.0002	0.02
Mac 1* - 4" Sewer Pipe	8/9/77	13.6	14.5	0.9	54	110-120	14.5	*0.9	0.0006	0.06
Mac 1 - 7½" Sewer Pipe	8/5/77	27.6	146.1	118.5	63-3/4	110-120	143.3	115.7	2.8	2.4
Mac 1* - 15" Sewer Pipe	8/9/77	12.7	15.0	2.4	54	110-120	15.1	*2.4	0.0075	0.31
Mac 1 - 22" Sewer Pipe	8/5/77	24.5	129.4	104.9	63-3/4	110-120	126.1	101.6	3.3	3.1
Mac 1 - 31" Sewer Pipe	8/5/77* 8/9/77	25.9 [illegible]	139.4 [illegible]	113.5 [illegible]	54 [illegible]	110-120 [illegible]	136.3 [illegible]	110.4 [illegible]	3.1 [illegible]	2.7 [illegible]

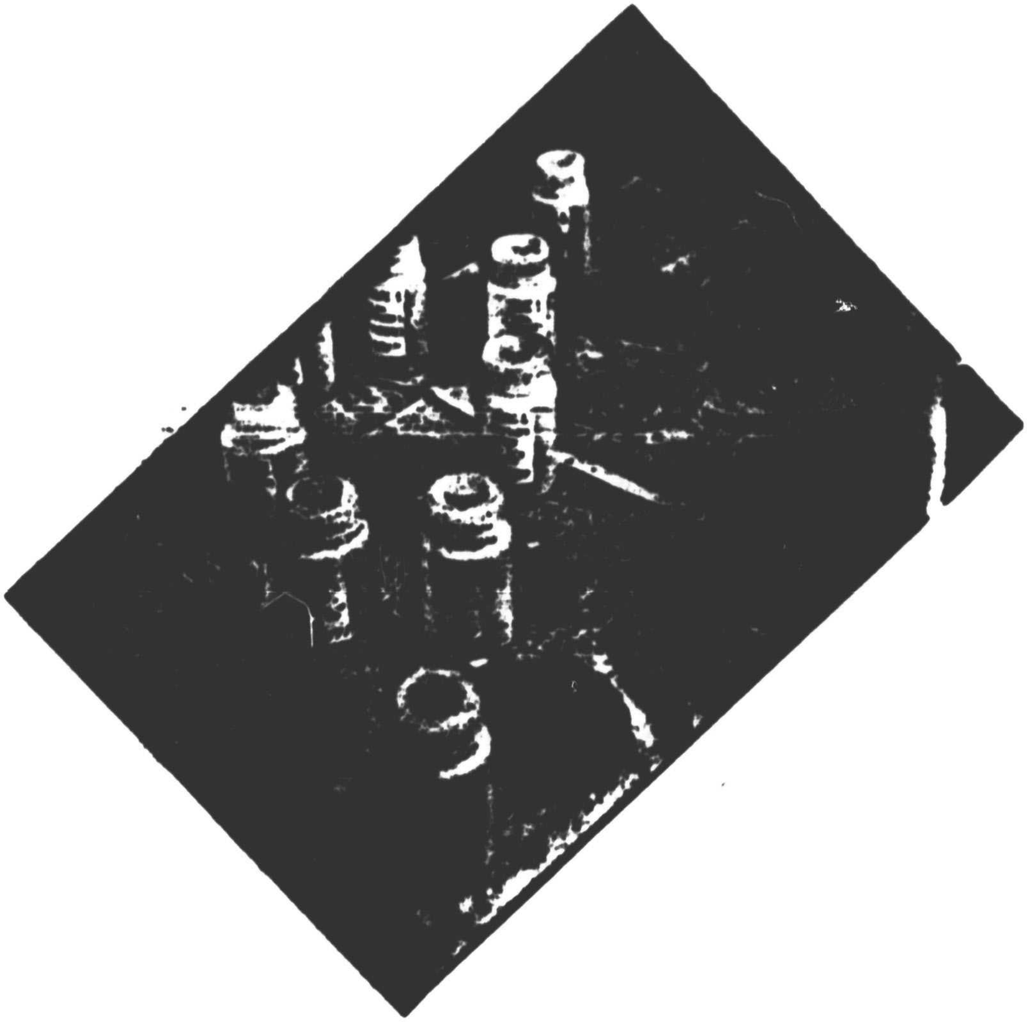

Plate 5c. SOIL SAMPLES AFTER OVER DRYING. NOTE THE COARSE TEXTURE OF THE SAMPLE IN LEFT CORNER, FROM THE DUMP SITE SURFACE BY THE "SEWER"PIPE INSTALLATION. NOTE ALSO THE FINE YELLOW SAMPLE JUST BENEATH THE COARSE SAMPLE. THIS SOIL WAS FROM THE DUMP SITE SEWER PIPE LOCALITY 4.5 INCHES BELOW THE SURFACE, AND WETTER THAN THE OTHERS.

APPENDIX 5: CALIBRATION OF THE PRT-4 AND PRT-5 UNITS

To calibrate the PRT instruments a black body filled with well mixed water was used as the sensing target. The temperature of the water measured by a reliable thermometer probe was compared to the PRT reading of the water temperature.

Table 5-1 lists temperatures taken with this equipment using a mercury thermometer to measure the water temperature. Voltmeter readings from the PRT are recorded in the column following the PRT-5 meter readings. The letter after the voltage indicates the scale of the reading; high, medium, or low. The next column lists the temperature equivalent of the voltage. The difference between the temperature from the PRT-5 meter and the equivalent voltage temperature is listed in the next column. The last two columns show the difference between the PRT-5 meter readings and the voltmeter temperature readings.

Figure 5-1 is a graph showing the difference between the voltage temperature of the water and the measured water temperature as a function of the voltmeter temperatures. The two curves show the trends for the medium and high range.

Figure 5-2 is a plot of the PRT-5 voltage temperature versus the water-bath temperature for both the medium and high range readings.

An attempt was made to determine the effects of the ambient air temperature by comparing readings with hot air blasting the PRT-5 sensor head with cooler air surroundings. No effect was detected. While running this experiment, a new set of data was recorded. Table 5-2 summarizes this new data set in the same format as Table 5-1. Figures 5-3 and 5-4 present this new data.

The PRT-4 was calibrated the same way as the PRT-5. Table 5-3 summarizes the resulting data. However, no tables were available to convert voltages into temperature. Note also that readings within 2°F were as accurate as could be made.

Figure 5-5 is a plot of the PRT-4 voltmeter readings as a function of the temperature readings of the waterbath. Figure 5-6 attempts to relate PRT-4 meter readings to the voltage readings. The relationship is described by the equation of the plotted line.

The accuracy of the PRT-4 may be shown by Figure 5-7 which compares the PRT-4 readings to the measured water temperature. Table 5-4 lists the calibration data obtained the evening before the field study was begun. The format of this chart is the same as for the previous tables.

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TABLE 5-1: Calibration of PRT-5 Meter Readings

Date	PRT-5 Meter °C	Volt-Meter mV	Volt-Meter °C	PRT-5 Voltmeter °C	Thermometer °C	PRT-5 Thermometer °C	Voltmeter-Thermometer °C
8/1/77	52.0	+308h	51.3	+0.7	----	----	----
In Lab	51.5	+296h	50.9	+0.6	----	----	----
(A-16)	51.0	+270h	50.0	+1.0	----	----	----
	50.5	+266h	49.8	+0.7	----	----	----
	50.0	+249h	49.2	+0.8	----	----	----
	49.5	+239h	48.8	+0.7	49.2	+0.3	-0.4
	49.0	+230h	48.5	+0.5	48.8	+0.2	-0.3
	48.5	+210h	47.8	+0.7	48.6	-0.1	-0.8
	48.0	+200h	47.5	+0.5	48.5	-0.5	-1.0
	47.5	+184h	46.9	+0.6	48.0	-0.5	-1.1
	47.0	+168h	46.3	+0.7	47.4	-0.4	-1.1
	46.5	+161h	46.1	+0.4	47.0	-0.5	-0.9
	46.0	+137h	45.2	+0.8	46.2	-0.2	-1.0
	45.5	+133h	45.1	+0.4	15.8	-0.3	-0.7
	45.0	+120h	44.6	+0.4	45.4	-0.4	-0.8
	44.5	+107h	44.1	+0.4	44.9	-0.4	-0.8
	*43.5	+945m	43.1	+0.4	44.9	-1.4	-1.8
	43.1	+948m	43.2	-0.1	44.6	-1.5	-1.4
	44.3	+100h	43.9	+0.4	44.6	-0.3	-0.7
	43.5	+072h	42.8	+0.7	43.5	0.0	-0.7
	43.0	+062h	42.4	+0.6	43.1	-0.1	-0.7
	42.5	+917m	42.2	+0.3	43.9	-1.4	-1.7
	42.5	+055h	42.2	+0.3	42.6	-0.1	-0.4
	42.0	+040h	41.6	+0.4	41.8	-0.2	-0.2
	42.0	+864m	40.3	+1.7	41.8	-0.2	-1.5
	41.5	+883m	41.0	+0.5	42.5	-1.0	-1.5
	41.5	+027h	41.1	+0.4	41.4	+0.1	-0.3
	41.0	+011h	40.4	+0.6	40.7	+0.3	-0.3
	40.5	+000h	40.0	+0.5	40.3	+0.2	-0.3
	40.0	+832m	39.1	+0.9	40.7	-0.7	-1.6
	39.5	+821m	38.8	+0.7	40.3	-0.8	-1.5
	39.0	+800m	38.1	+0.9	39.5	-0.5	-1.4
	38.5	+793m	37.9	+0.6	39.3	-0.8	-1.4
	*37.0	+741m	36.2	+0.8	37.3	-0.3	-1.1
	*36.7	+730m	35.8	+0.9	37.0	-0.3	-1.2
	*29.5	+517m	28.7	+0.8	29.4	+0.1	-0.7
	*28.0	+472m	27.2	+0.8	27.3	+0.7	-0.1
	*27.2	+448m	26.4	+0.8	26.3	+0.9	+0.1
	*26.5	+424m	25.6	+0.9	25.4	+1.1	+0.2
	*25.3	+424m	25.6	-0.3	25.3	0.0	+0.3
	*22.5	+319m	21.9	+0.6	21.9	+0.6	0.0
	*21.5	+287m	20.8	+0.7	20.4	+1.1	+0.4
	*20.5	+260m	19.8	+0.7	19.0	+1.5	+0.8
	*19.0	+223m	18.5	+0.5	17.5	+1.5	+1.0
	18.5	+205m	17.8	+0.7	16.6	+1.9	+1.2
	*17.5	+178m	16.9	+0.6	15.3	+2.2	+1.6
	17.0	+166m	16.4	0.6	14.9	+2.1	+1.5

TABLE 5-1 (continued)

Date	PRT-5 Meter °C	Volt-Meter mV	Volt-Meter °C	PRT-5 Voltmeter °C	Thermometer °C	PRT-5 Thermometer °C	Voltmeter-Thermometer °C
8/1/77	16.5	+153m	16.0	+0.5	14.5	+2.0	+1.5
In Lab	*15.7	+132m	15.2	+0.5	13.5	+2.2	+1.7
(A-16)	15.0	+110m	14.3	+0.7	12.5	+2.5	+1.8
	45.5	+102h	43.9	+1.6	Mirror		
	43.5	+951m	43.3	+0.2	Mirror		

M. KELLEN

CALIBRATION OF PRT-5 VOLTMETER
TEMPERATURE READINGS
8/1/77

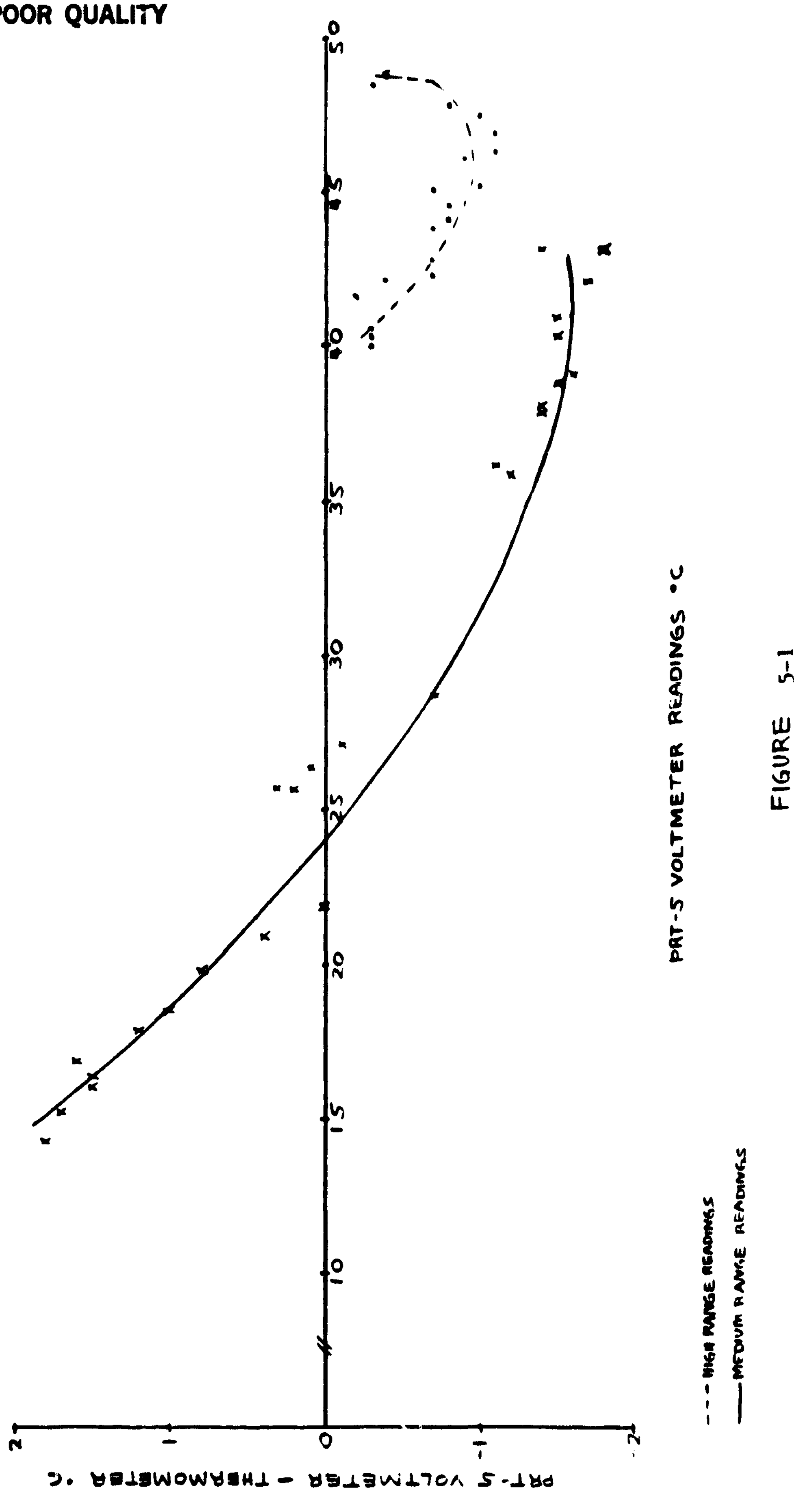

FIGURE 5-1

CALIBRATION OF PRT-5 VOLTMETER
TEMPERATURE READINGS
8/1/77

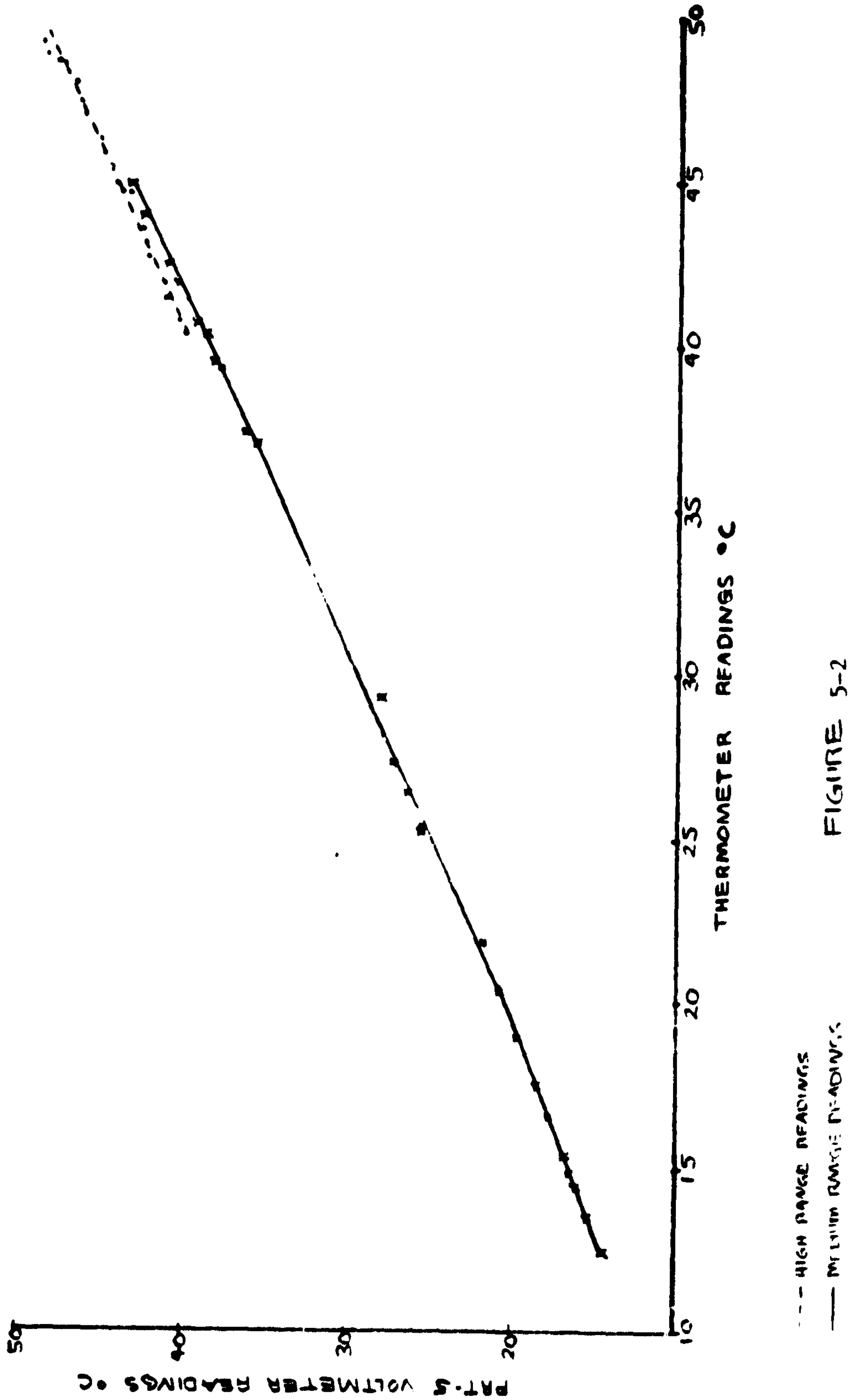

FIGURE 5-2

TABLE 5-2: Calibration of PRT-5 Meter Readings

Date	PRT-5 Meter °C	Volt-Meter V	Volt-Meter °C	Voltmeter	Thermometer (5810-1)°C	PRT-5 Thermometer °C	Voltmeter-Thermometer °C
8/27/77	74.8	+.987h	74.6	0.2	74.2	+0.6	+0.4
In Lab	70.5	+.848h	69.7	+0.8	69.6	+0.5	+0.1
(A-16)	69.8	+.828h	68.9	+0.9	68.6	+1.2	+0.3
	68.5	+.793h	67.7	+0.8	67.0	+1.5	+0.7
	65.6	+.705h	64.8	+0.8	66.1	-0.5	-1.3
	64.5	+.670h	63.6	+0.9	65.1	-0.6	-1.5
	61.2	+.574h	60.4	+0.8	62.1	-0.9	-1.7
	60.2	+.541h	59.2	+1.0	60.4	-0.2	-1.2
	57.0	+.444h	56.1	+0.9	57.1	-0.1	-1.0
	53.8	+.360h	53.1	+0.7	54.0	-0.2	-1.0
	52.5	+.321h	51.8	+0.7	52.4	+0.1	-0.6
	50.4	+.261h	49.6	+0.8	50.5	-0.1	-0.4
	49.5	+.238h	48.8	+0.7	49.5	0.0	-0.7
	48.5	+.213h	47.9	+0.6	47.7	+0.8	+0.2
	47.0	+.173h	46.5	+0.5	46.1	+0.9	+0.4
	46.5	+.152h	45.8	+0.7	46.0	+0.5	-0.2
	45.5	+.132h	45.0	+0.5	45.1	+0.4	-0.1
	44.5	+.101h	43.9	+0.6	43.8	+0.7	+0.1
	44.2	+.094h	43.6	+0.6	43.6	+0.6	0.0
	42.5	+.924m	42.4	+0.1	43.6	-1.1	-1.2
	42.8	+.056h	42.2	+0.6	42.0	+0.8	+0.2
	41.5	+.886m	41.1	+0.4	42.0	-0.5	-0.9
	42.0	+.032h	41.7	+0.3	41.0	+1.0	+0.7
	41.5	+.858m	40.1	+1.4	41.0	+0.5	-0.9
	*40.5	+.000h	40.0	+0.5	39.6	+0.9	+0.4
	39.0	+.809m	38.4	+0.6	39.8	-0.8	-1.4
	38.8	+.804m	38.3	+0.5	39.0	-0.2	-0.7
	38.0	+.777m	37.4	+0.6	38.0	+0.0	-0.6
	37.4	+.748m	36.4	+1.0	37.1	+0.3	-0.7
	36.5	+.728m	35.8	+0.7	36.2	+0.3	-0.4
	35.5	+.644m	34.7	+0.8	35.3	+0.2	-0.6
	34.1	+.651m	33.2	+0.9	33.9	+0.2	-0.7
	33.4	+.629m	32.5	+0.9	32.8	+0.6	-0.3
	32.5	+.606m	31.7	+0.8	31.9	+0.6	-0.2
	31.5	+.577m	30.7	+0.8	30.8	+0.7	-0.1
	31.0	+.558m	30.1	+0.9	30.1	+0.9	0.0
	30.3	+.538m	27.4	+0.9	28.9	+0.4	+0.5
	29.0	+.503m	28.3	+0.7	27.9	+1.1	+0.4
	28.4	+.482m	27.6	+0.8	27.2	+1.2	+0.4
	28.0	+.469m	27.1	+0.9	26.7	+1.3	+0.4
	27.1	+.445m	26.3	+0.8	25.7	+1.4	+0.6
	26.5	+.430m	25.8	+0.7	25.1	+1.4	+0.7
	25.5	+.402m	24.8	+0.7	24.0	+1.5	+0.8
	24.5	+.370m	23.7	+0.8	22.7	+1.8	+1.0
	23.6	+.347m	22.8	+0.8	21.8	+1.8	+1.0
	23.1	+.333m	22.4	+0.7	21.3	+1.8	+1.1
	22.5	+.314m	21.8	+0.7	20.5	+2.0	+1.3

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TABLE 5-2 (continued)

Date	PRT-5 Meter °C	Volt-Meter V	Volt-Meter °C	Voltmeter	Thermometer (5810-1)°C	PRT-5 Thermometer °C	Voltmeter-Thermometer °C
8/27/77 In Lab (A-16)	21.8	+.296m	21.1	+0.7	19.8	+2.0	+1.3
	21.3	+.283m	20.7	+0.6	19.2	+2.1	+1.5
	20.6	+.265m	20.0	+0.6	18.7	+1.9	+1.3
	20.0	+.244m	19.3	+0.7	17.8	+2.2	+1.5
	19.5	+.233m	18.9	+0.6	17.2	+2.3	+1.7
	18.8	+.216m	18.2	+0.6	16.6	+2.2	+1.6
	18.5	+.203m	17.7	+0.8	16.1	+2.4	+1.6
	17.8	+.190m	17.3	+0.5	15.6	+2.2	+1.7
	17.5	+.180m	16.9	+0.6	15.1	+2.4	+1.8
	17.0	+.165m	16.4	+0.6	14.5	+2.5	+1.9
	16.5	+.155m	16.0	+0.5	14.0	+2.5	+2.0
	16.1	+.144m	15.6	+0.5	13.6	+2.5	+2.0
	15.5	+.130m	15.1	+0.4	12.6	+2.9	+2.5
	14.0	+.970ℓ	14.0	+0.0	12.6	+1.4	+1.4
	15.0	+.112m	14.4	+0.6	12.2	+2.8	+2.2
	13.5	+.952ℓ	13.4	+0.1	12.2	+1.3	+1.2
	14.2	+.093m	13.7	+0.5	11.2	+3.0	+2.5
	12.6	+.923ℓ	12.4	0.2	11.2	+1.4	+1.2
	13.5	+.073m	12.9	+0.6	10.4	+3.1	+2.5
	12.0	+.896ℓ	11.5	+0.5	10.4	+1.6	+1.1
	13.0	+.063m	12.5	+0.5	10.0	+3.0	+2.5
	11.5	+.879ℓ	11.0	+0.5	10.0	+1.5	+1.0
	41.0	-.106h			mirror		
	43.5	953m			mirror		

M. KELLER

CALIBRATION OF PRT-5 VOLTMETER
TEMPERATURE READINGS
8/27/77

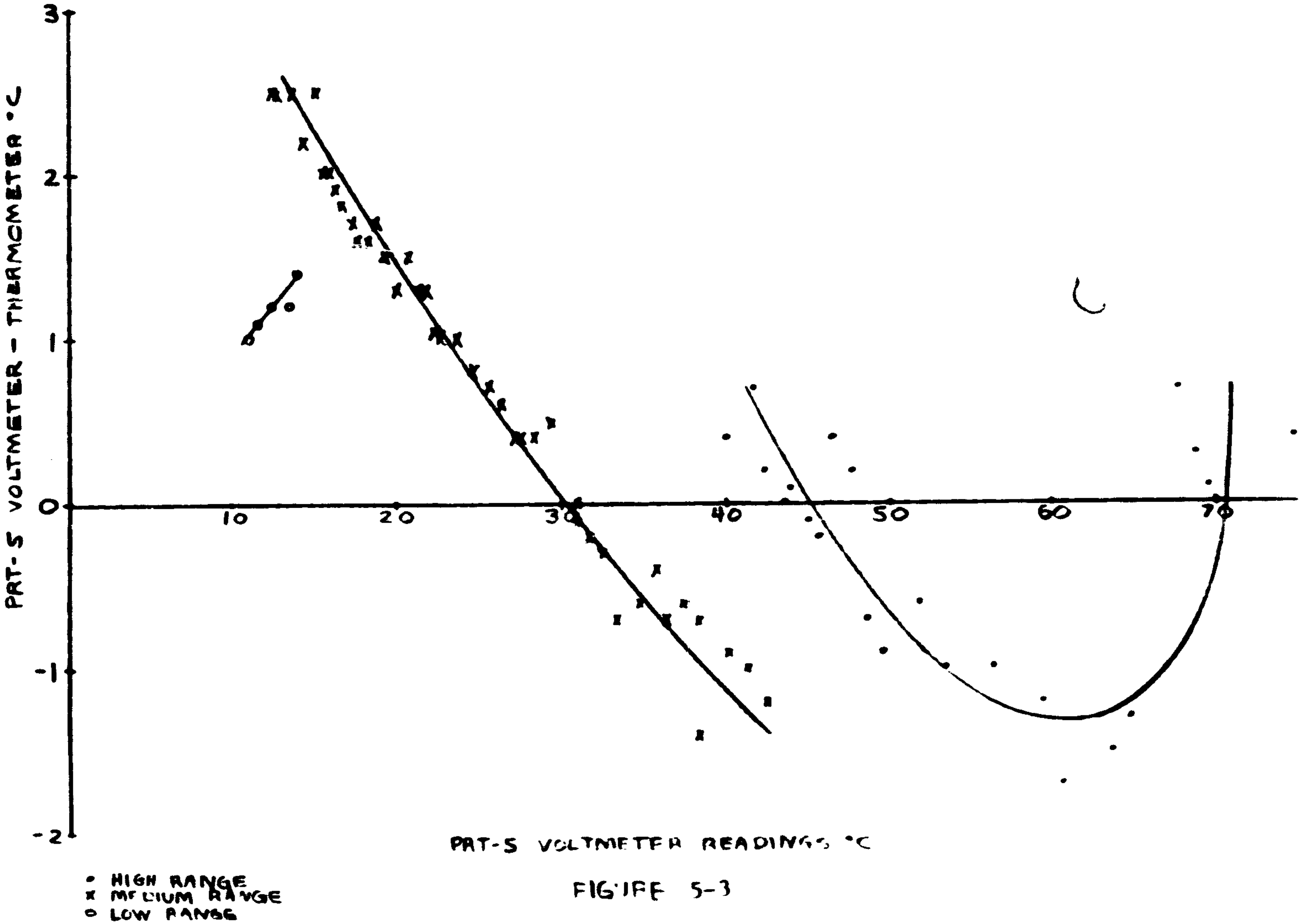
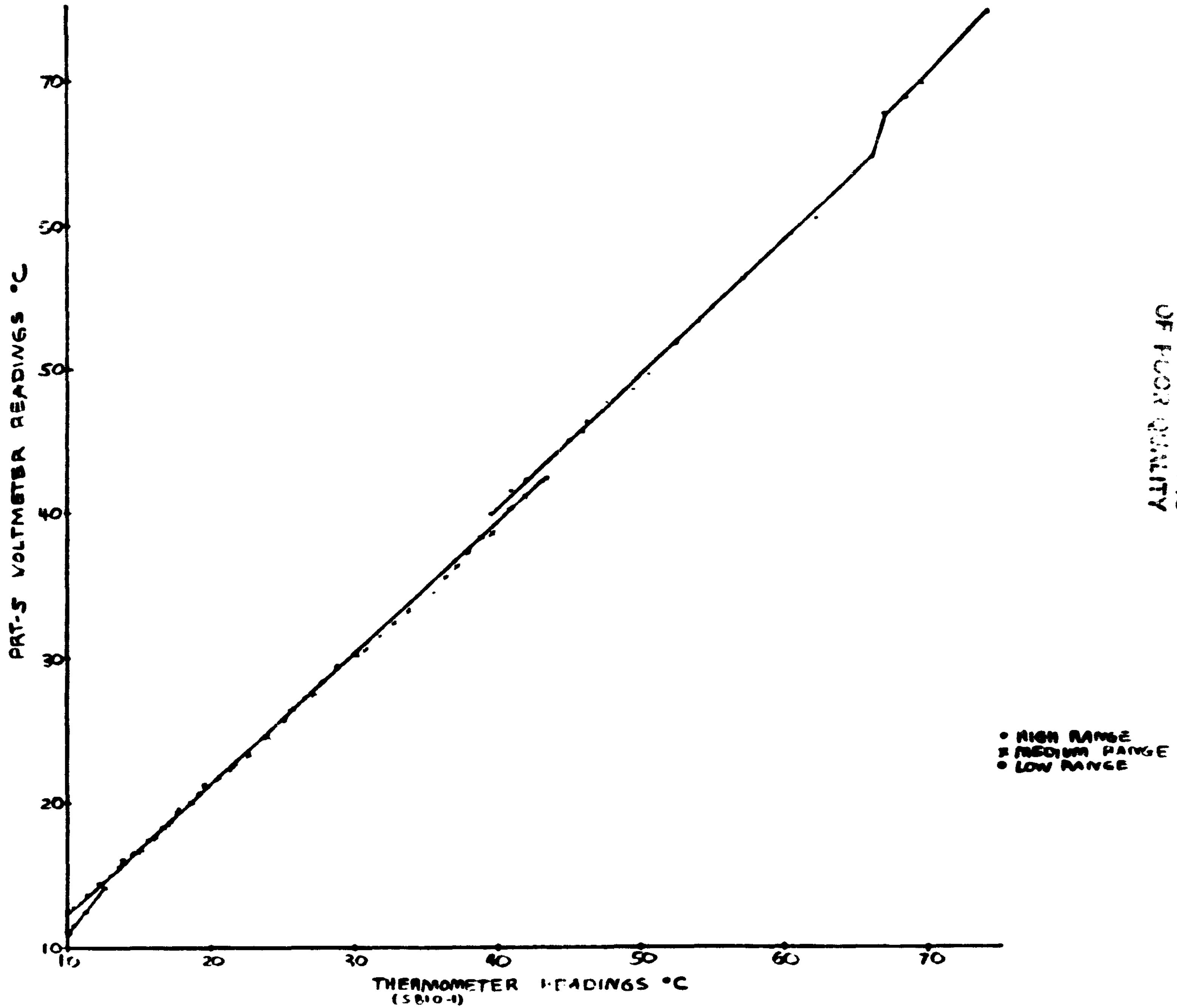


FIGURE 5-3

CALIBRATION OF PRT-5 VOLTMETER
TEMPERATURE READINGS
8/27/77



FIGURE

TABLE 5-3: Calibration of PRT-4 Meter Readings

Date	PRT-4 Meter of	Volt-Meter V	Thermometer (5810-1)°C	PRT-4 Meter °C	PRT-4 Thermometer °C
8/27/77	> 110	+.016	56.3	> 43.3	----
In Lab	> 110	+.015	54.8	> 43.3	----
(A-16)	> 110	+.018	53.1	> 43.3	----
	> 110	+.023	52.6	> 4.33	----
	> 110	+.028	51.8	> 43.3	----
	> 110	+.041	48.9	> 43.3	----
	> 110	+.043	47.8	> 43.3	----
	> 110	+.051	47.0	> 43.3	----
	> 110	+.054	46.1	> 43.3	----
	> 110	+.064	45.0	> 43.3	----
	> 110	+.071	43.4	> 43.3	----
	> 110	+.080	41.8	> 43.3	----
	107-109	+.093	39.2	42.2	+3.0
	104-106	+.096	38.2	40.6	+2.4
	103-105	+.100	37.4	40.0	+2.6
	102-104	+.104	36.4	39.4	+3.0
	100-102	+.109	35.4	38.3	+2.9
	97-99	+.114	34.0	36.7	+2.7
	96-98	+.119	32.9	36.1	+3.2
	94-96	+.122	31.9	35.0	+3.1
	92-94	+.128	30.8	33.9	+3.1
	91-93	+.132	30.1	33.3	+3.2
	90-92	+.135	28.9	32.8	+3.9
	88-90	+.140	27.9	31.7	+3.8
	86-88	+.142	27.1	30.6	+3.5
	86-88	+.144	26.7	30.6	+3.9
	84-86	+.150	25.7	29.4	+3.7
	84-86	+.151	25.1	29.4	+4.3
	82-84	+.154	24.0	28.3	+4.3
	80-82	+.157	23.4	27.2	+3.8
	79-81	+.161	22.6	26.7	+4.1
	78-80	+.163	21.8	26.1	+4.3
	77-79	+.166	21.4	25.6	+4.2
	75-77	+.168	20.5	24.4	+3.9
	74-76	+.170	19.8	23.9	+4.1
	74-76	+.175	19.1	23.9	+4.8
	73-75	+.173	18.8	23.3	+4.5
	72-74	+.173	18.4	22.8	+4.4
	70-72	+.179	17.2	21.7	+4.5
	70-72	+.180	16.6	21.7	+5.1
	68-70	+.183	16.1	20.6	+4.5
	68-70	+.184	15.6	20.6	+5.0
	67-69	+.187	15.1	20.0	+4.9
	66-68	+.187	14.5	19.4	+4.7
	65-67	+.190	14.0	18.9	+4.9
	64-66	+.192	13.6	18.3	+4.7
	62-64	+.196	12.7	17.2	+4.5
	62-64	+.196	12.2	17.2	+5.0
	89-90		mirror	32	

CALIBRATION OF PRT-4 VOLTMETER
TEMPERATURE READINGS
8/27/77

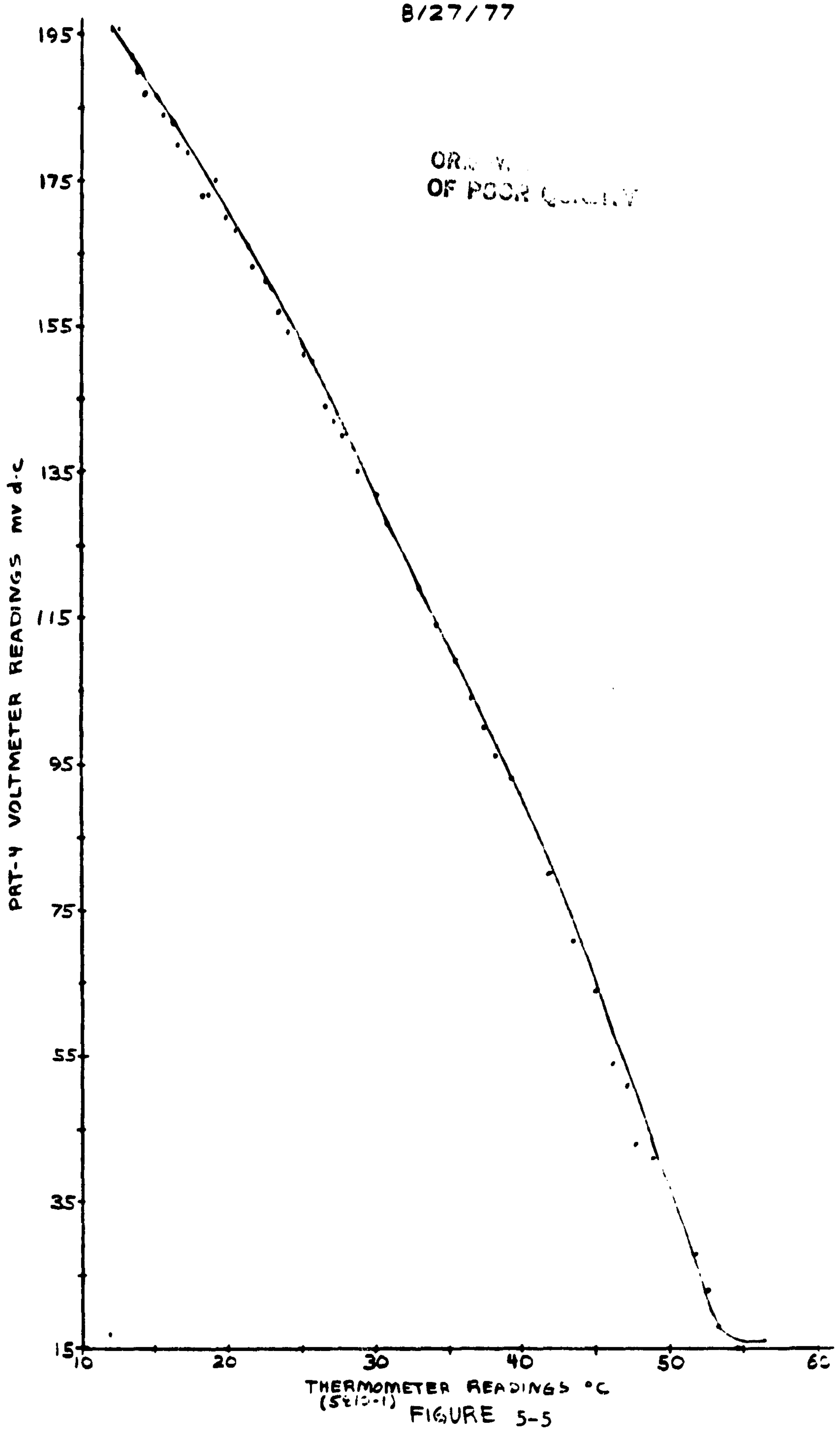


FIGURE 5-5

CALIBRATION OF PRT-4 METER READINGS
8/27/77

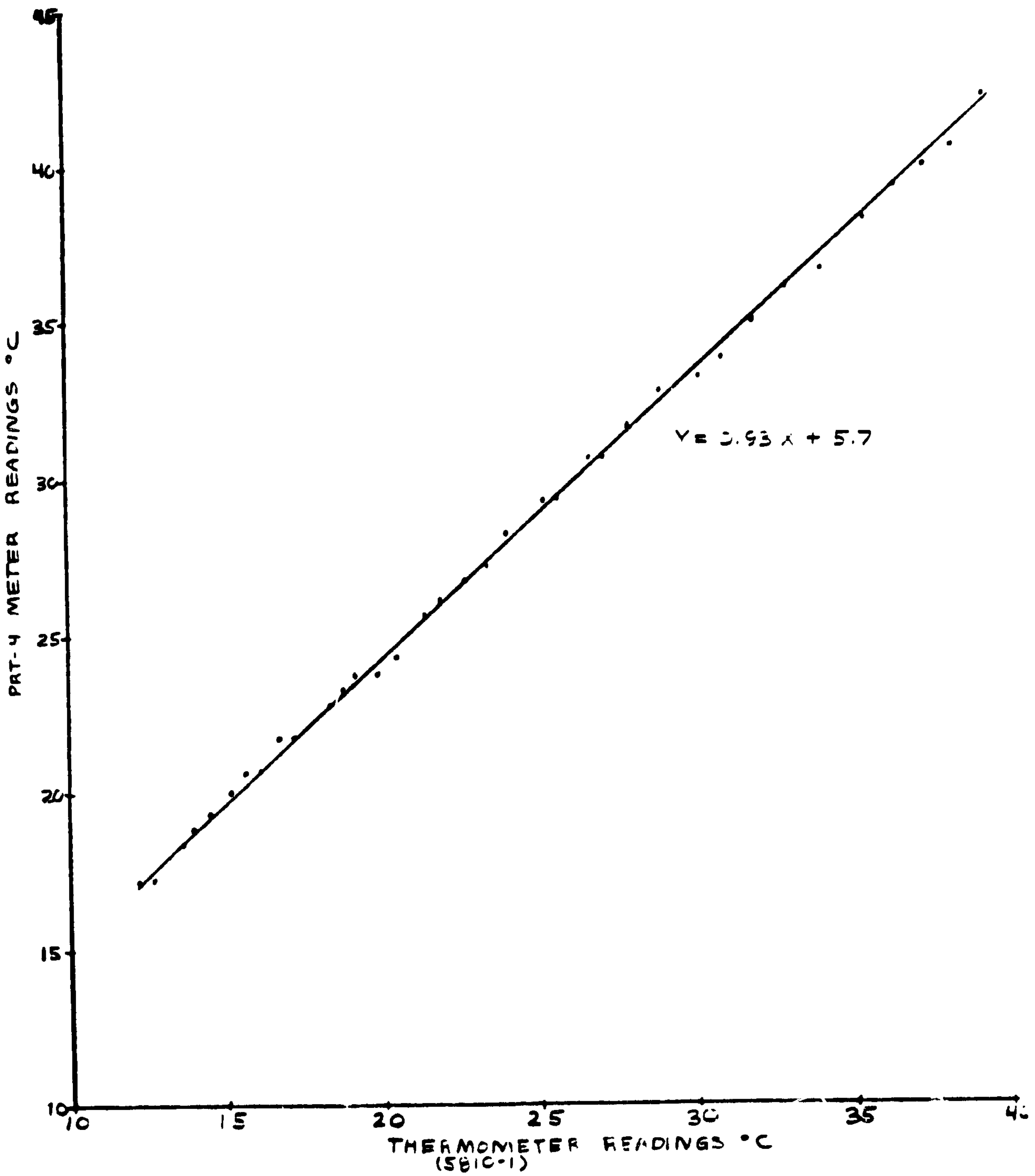


FIGURE 5-6

CALIBRATION OF PRT-4 METER READINGS

8/27/77

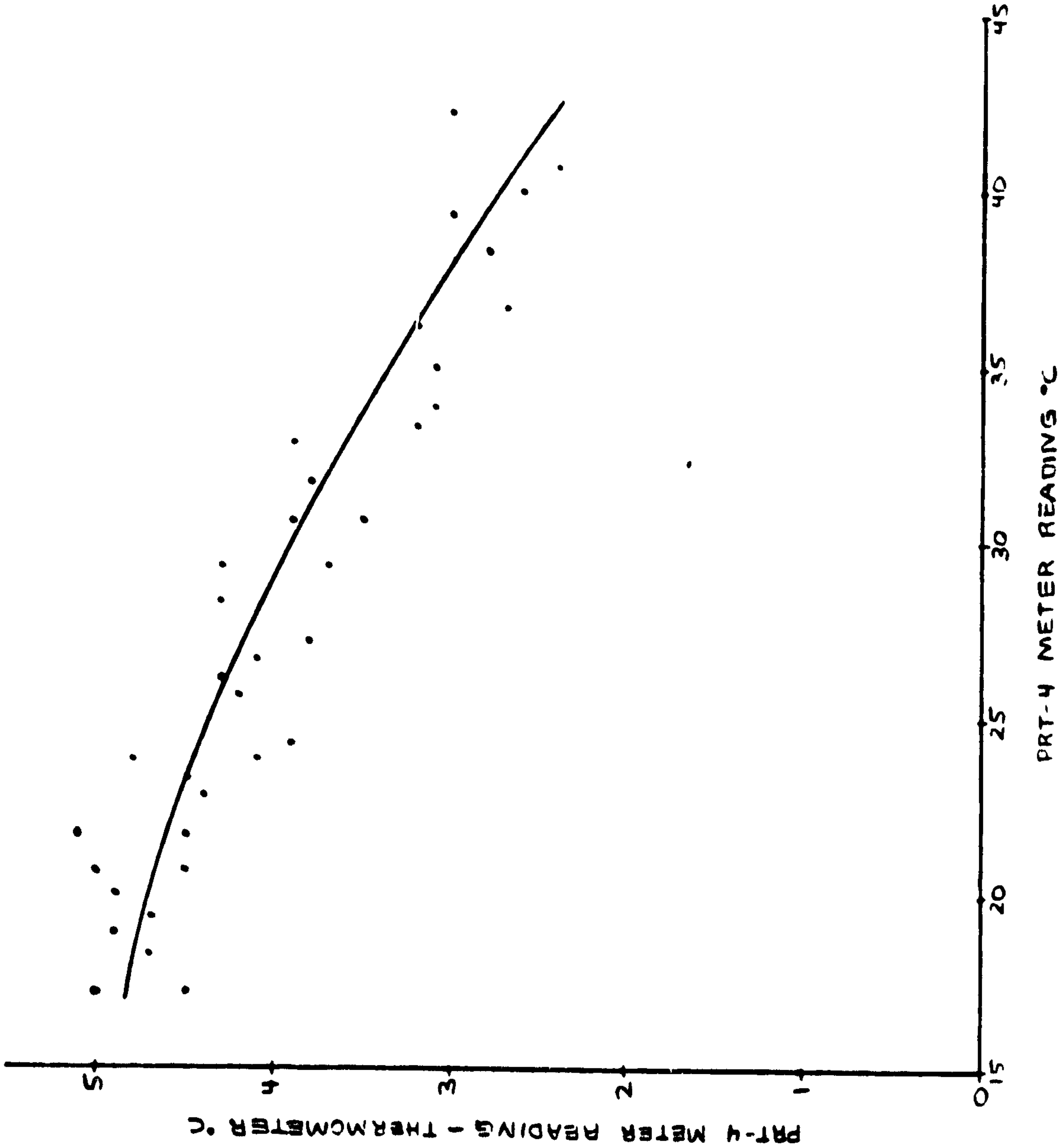


FIGURE 5-7

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TABLE 5-4: Calibration of PRT-4 and PRT-5

Date	PRT-5 Meter °C	Volt-Meter mV	Volt-Meter °C	PRT-5-Voltmeter °C	Thermometer °C	PRT-5 *Thermometer °C	Voltmeter-Thermometer °C	PRT-4 Meter of	Thermom-eter °C	Thermom-eter °C
8/7/77	18.0	197m	17.5	+0.5	17.0	+1.0	+0.5			
	24.5	372m	23.8	+0.7	24.0	+0.5	-0.2			
	25.0	381m	24.1	+0.9	24.0	+1.0	+0.1			
	26.0	417m	25.4	+0.6	25.3	+0.7	+0.1			
	28.8	491m	27.9	+0.9	28.2	+0.6	-0.3			
	33.0	618m	32.1	+0.9	33.5	-0.5	-1.4			
	35.3	682m	34.3	+1.0	35.5	-0.2	-1.2			
	37.5	753m	36.6	+0.9	38.8	-1.3	-2.2			
	40.5	840m	39.4	+1.1	41.5	-1.0	-2.1			
	41.5	017h	40.7	+0.8	41.5	0.0	-0.8			
	44.0	962m	43.7	+0.3	----	----	----			
8/7/77								56-58	12.0	1.89
								72-74	19.0	3.78
								88-90	28.0	3.67
								101-103	38.0	0.89

APPENDIX 6

PHOTOGRAPHS OF FIELD WORK AUGUST 1977

Plate 5a. LOOKING S OF LEACH POND WITH RECORDING THERMOMETERS,TOWARDS A HEMATICALLY-STAINED TAILINGS PILE

Plate 5b. WALKER RIVER NEAR YERINGTON,NEVADA

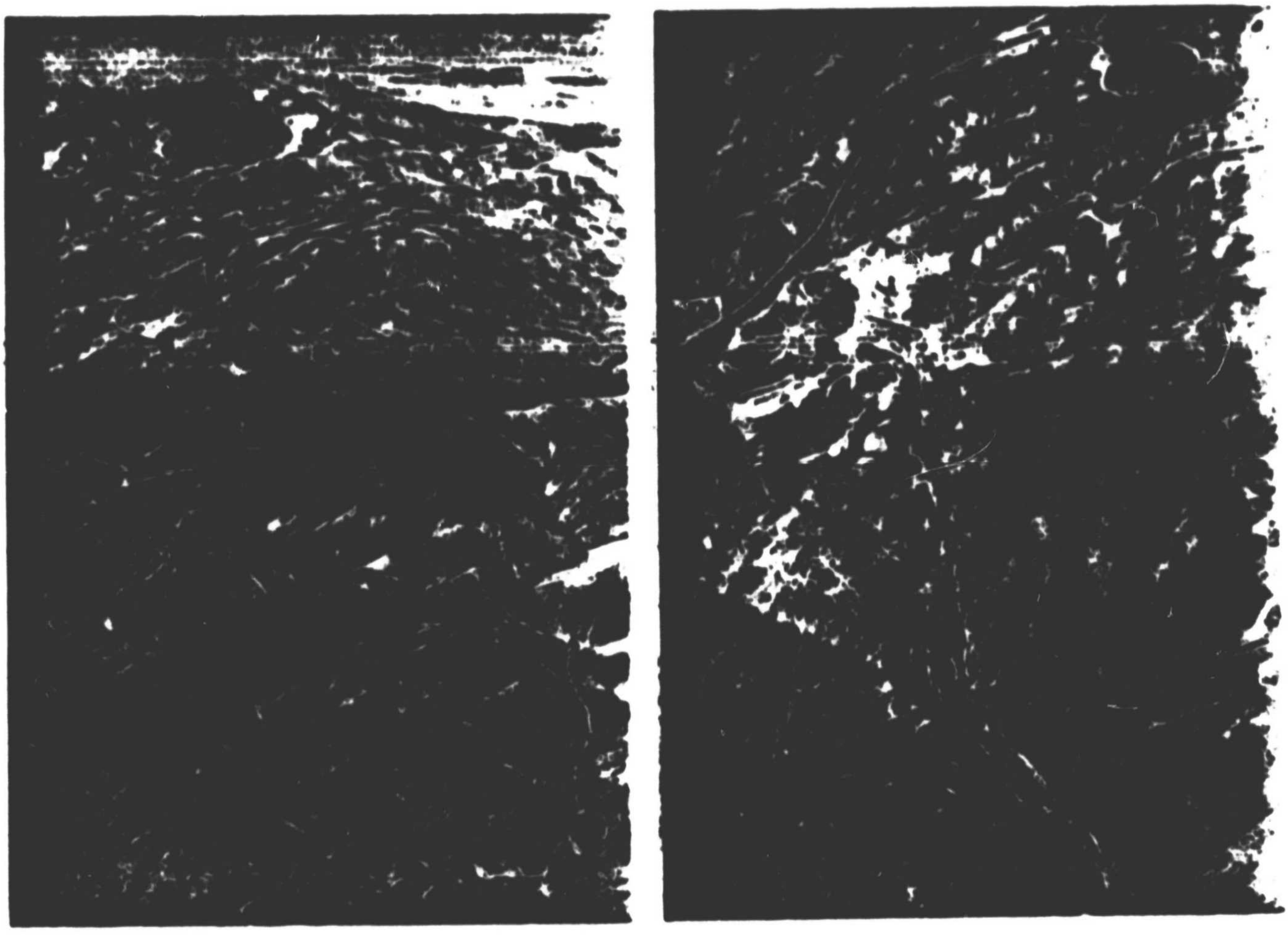

Plate 6. SINGATSE RANGE FROM THE AIR, WESTERN NEVADA, 8/5/77

APPENDIX 7

REPORT ON THERMAL-INERTIA RELATED COMPUTER PROGRAMS FS6 & FSFL2 (CSIROTEMP) WATSON, SURTEMP

by

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It is difficult to compare the four programs on the basis of complexity, for they differ widely in purpose: FS6 attempts to fit observed temperature data by adjusting two or three parameters (with others held fixed), while WATSON merely calculates diurnal temperature curves corresponding to a series of input parameters, any given one of which may be assigned multiple values for a family of curves. The machinery required to allow selection of any parameter as the 'variable' with multiple values makes WATSON appear much more complex than it otherwise would. SURTEMP and FSFL2 merely accept a full set of input parameters and calculate a temperature curve ; they lack as well the plotting routines shared by the other two programs. FS6 reads data from and writes to text files, while the other programs deal interactively with the keyboard user.

FS6, FSFL2, and WATSON employ modifications of the same algorithm, fourier decomposition of the solar heat flux, linearization of other heat flux terms, and fourier representation of the surface temperature. They differ in that FS6 attempts to fit obeserved temperature data whereas WATSON merely calculates one or more diurnal curves, and as well in the complexity of their parameter sets. WATSON includes the effects of emissivity, cloud cover, and geothermal flux, while FS6 lumps all nonsolar flux terms into a single variable. FSFL2 is an earlier, nonfitting version of FS6, which includes the effects of sensible heat transfer and longwave radiation from both earth and sky, but not cloud cover or slope. SURTEMP has a parameter set similar to WATSON, but utilizes an entirely different algorithm. The Laplace transform method of Jaeger is used to express the total thermal flux required to maintain a periodically recurring temperature curve (discretized into a twenty-point series) on the basis of heat conduction in the earth. Models of solar flux, longwave emission, and so on give a second expression for the fluxes as a function of the temperatures at the twenty times. A least-squares fitting routine adjusts the

temperature until the two experssions are consistent. A set of observed Temperatures may be read in and printed out for comparison, but are not used in the calculation. It is worthwhile to emphasize that, though FS6 and SURTEMO Utilize the same least-squares routines, they use them for entirely different purposes. In SURTEMP, they find a set of temperatures which satisfy the heat flux requirements for periodicity, given certain other parameters such as thermal inertia. In FS6, they operate on the temperature curve as a given vector-valued function of the thermal inertia and other parameters, which they adjust to modify the solution.

A brief description of the computations involved in each program is given below, followed by a discussion of the various mathematical approaches to the heat equation problem. I have attempted to convert the symbology of the Jaeger and Watson papers and the three programs to the following consistent set:

Thermal Inertia	P
Albedo	A
Emissivity	ε
Air Temperature	T_{air}
Sky temperature (mean)	$\bar{T}_{sky}$
Sky temperature (day)	T_D
Sky temperature (night)	T_N
Latitude	λ
Solar Declination	δ
Solar zenith angle	Z
Local surface dip	d
Strike	s
Atmospheric transmissivity	M
Air pressure	P
Water content	W
Dust content	CD
Von Karman's constant	k
Wind Friction velocity	U_*
Surface roughness length	z_o
Height of meterologic observations	z

Stability-dependent profile function	$\Delta\psi_m$
Mean surface-air temperature difference	$\Delta\bar{T}$
Ratio of sky to earth emissivity	c
Free sky fraction	C
Solar constant	S_o
Observed ground temperature	T
Calculated ground temperatures	V
Diurnal angular frequency	ω
Time (from noon)	t
Total heat flux	F
Geothermal flux	Q
Solar flux	I
Fourier amplitude & phase of solar flux	A_n, ϵ_n
Sine and cosine amplitudes of solar flux	A_n, ϵ_n
Thickness of layer over the half-space	l
Thermal inertia of covering layer	P_l
Diffusivity of covering layer	κ

Calculation proceeds exactly as in FS6, except that the linear heat-transfer term includes not only upward longwave radiation, but downward radiation and sensible heat loss as well, using the assumptions that air temperature is a linear function of ground temperature, and sky temperature proportional to air temperature:

$$G = W(1-\beta) + \varepsilon\sigma \quad (4\bar{V}^3 - 4c_\beta \; (\bar{V}-\Delta\bar{T})^3)$$

$$\beta = \frac{\ln\left(0.8905\ \sqrt{w(z+z_0)/kU_*}\right)}{\ln\left(0.8905\ \sqrt{wz_0/kU_*}\right)}$$

so that $T_{air} - \bar{T}_{air} = \beta(V-\bar{V})$

Once the values of temperature V are known, rather than adjusting them by altering P, G, and $\bar{V}$ as in FS6, the program calculates and prints each of the terms in the energy budget for each point in time:

$T_{air} = \bar{T}_{air} + \beta(V(t)-\bar{V})$, $I(t)$, $I(t) + \varepsilon\sigma(cT_{air}^4 - V^4)$,

$H(t) = W(T_{air} - V)$, and $F(t)$.

WATSON

(latest version implemented by T.E. Townsend)

Input parameters: $P, A, \varepsilon, \lambda, \delta, \bar{T}_{sky}, d, s, Q, C$

Any one parameter may have 2-5 values, while all others have one.

The solar irradiance is modeled by the equations:

$$M = 1 - 1/5.(\cos(\lambda)\cos(\delta)\cos(\omega t) - \sin(\lambda)\sin(\delta))^{\frac{1}{2}}$$

$$\cos(Z) = \cos(\lambda)\cos(\delta)\cos(d)\cos(\omega t) + \cos(\lambda)\sin(\delta)\sin(d)\sin(\omega t)$$

$$- \sin(\lambda)\cos(\delta)\sin(d)\cos(s)\cos(\omega t) - \sin(\lambda)\sin(\delta)\cos(d)\cos(s)$$

$I = M\cos(z)$

and evaluated at 99 equally-spaced points in time to yield by recursive calculation a 50-harmonic Fourier cosine-and-sine series:

$$I(t) = S_o \sum_{n=0}^{49} A_n \cos(n\omega t) + B_n \sin(n\omega t)$$

$$= S_o \sum_{n=0}^{49} (A_n - iB_n)\, e^{in\omega t}$$

The Fourier coefficients for the temperature are calculated by the complex-admittance method of Byrne and Davis, permitting inclusion in the model of a layer over the half-space with different thermal properties. The calculation is most simply expressed using the complex-exponential representation of the Fourier series:

$$V(t) = \bar{T}_{sky} + \frac{Q}{4\varepsilon\sigma\bar{T}^3_{sky}} + (1-A)\, S_o C \sum_{n=1}^{49} \frac{(A_n + iB_n)}{Y_n}\, e^{in\omega t}$$

where $Y_n = 4\varepsilon\sigma\bar{T}^3_{sky} + \sqrt{n\omega}\;\; P\, e^{i\pi/4}$

$$\frac{\frac{P_e}{P}\tanh\left(\sqrt{\frac{n\omega}{2K}}\; l\, e^{i\pi/4}\right) + 1}{(\tanh\left(\sqrt{\frac{n\omega}{2K}}\; l\, e^{i\pi/4}\right) + \frac{P_e}{P}}$$

In the case of no layer,

$P_l = P$, $l = 0$, and $Y_n = 4\varepsilon\sigma\bar{T}^3_{sky} + \sqrt{n\omega}\;\; P_e\, e^{i\pi/4}$

The mean temperature is calculated by the expression:

$$\bar{V} = (1-A)A_o C\, \frac{A_o}{Y_o} + \bar{T}_{sky} + \frac{Q}{4\varepsilon\sigma\bar{T}^3_{sky}}$$

$$= \frac{(1-A)S_o CA_o + Q}{4\varepsilon\sigma\bar{T}^3_{sky}} + \bar{T}_{sky}$$

Then for 49 equally-spaced times the temperature is evaluated:

$$V(t) = \bar{T}_{sky} + \frac{Q}{4\varepsilon\sigma\bar{T}^3_{sky}} + (1-A)S_o C \sum_{n=0}^{49} \{ (A_n \mathrm{Re}\left(\frac{1}{Y_n}\right) + B_n \mathrm{Im}\left(\frac{1}{Y_n}\right) \cos\, (n\omega t)$$

$$+ \left(B_n \mathrm{Re}\left(\frac{1}{Y_n}\right) - A_n \mathrm{Im}\left(\frac{1}{Y_n}\right)\right) \sin (n\omega^*))$$

and the resulting temperature curve plotted; the process is repeated for all values of the varying parameter.

SURTEMP

(oldest version of WATSON programs)

Input parameters: P, A, C, T_N, T_D, ε, λ, δ, d, s, (t, T(t)) pairs

The values of T will be printed out with the result V, but are never involved in calculation.

The model calculates all values at an evenly spaced set of twenty times, starting with the solar flux:

$$M = 1 - 1/5\ (\cos(\lambda)\cos(\delta)\cos(\omega t) + \sin(\lambda)\sin(\delta))^{\frac{1}{2}}$$

$$\cos(Z) = \begin{array}{l}\cos(\lambda - \delta\sin(s))\cos(\delta)\cos(\omega t + d\cos(s)) + \sin(\lambda-\delta\sin(s))\sin(\delta)\\ \text{or zero if this is negative}\end{array}$$

$$T_{sky} = \begin{array}{l}T_D,\ \cos(Z) > 0\\ T_N,\ \cos(Z) < 0\end{array}$$

$$I(t) = \frac{1}{30}\,C(1-A)M\cos(Z) + \varepsilon\sigma T_{sky}^4$$

The Jaeger method gives a prediction of the total heat flux into the ground required to sustain a periodic temperature curve:

$$F_i = \frac{P}{\pi}\sqrt{\frac{\omega}{2}}\sum_{j=1}^{20} V_i\ \ \phi_i{-j+1} \quad \text{where } Y_i \text{ are constants}$$

The program defines an error in the flux estimation:

$$\Delta F_i = F_i - I_i + \sigma\varepsilon V_i^4$$

and this is fit to zero as a function of the V_i's by a least squares method. The data re yped and pseudoplotted on the terminal. No options to fit exist, but the parameters may be adjusted and the calculations repeated.

FOURIER SERIES SOLUTIONS TO THE HEAT EQUATION: THERMAL INERTIA, THERMAL ADMITTANCE, AND THE G-FACTOR

Temperature-curve analysis is concerned with the solution of the heat-conduction equation

$$\rho C \frac{\partial T}{\partial T} = \frac{\partial}{\partial z} \quad K \frac{\partial T}{\partial t} = \frac{\partial G}{\partial t} \tag{1}$$

in the earth, with B.C. at the upper surface

$$I_{tot} + G + H + LE = 0 \tag{2}$$

where I_{tot} = total radiative flux, G = heat conduction into the earth, i.e. the heat flux in (1), H = sensible heat loss to the air, and LE = evaporative heat loss.

Solutions for the simplified case H = LE = 0, $I_{tot} = A\cos(\omega t) + B\sin(\omega t)$ $=(A^2 + B^2)^{\frac{1}{2}}\cos(wt - \tan^{-1}\frac{B}{A}) = (A-iB)\exp\{i(wt)\}$ is possible; we get

$$T\Big|_{z=0} = \frac{A - iB}{\sqrt{\omega}\ P} \exp\{i(\omega t - \frac{\pi}{4})\}$$

where $P = \sqrt{k}\ C$ is the thermal inertia. Dividing the temperature into the flux we can obtain the <u>admittance</u> (by analogy with admittance in A.C. electronics, where current corresponds to flux, and voltage to temperature).

$$Y = \frac{I}{T} = \sqrt{\omega}\, P\, e^{i\frac{\pi}{4}} \tag{3}$$

Note that Y is a function of both w and P, and that it is proportional to $e^{i\frac{\pi}{4}} = \frac{1+i}{\sqrt{2}}$ since T lags I by 45^o. The in-phase and quadrature components of I are equal in magnitude.

In the full problem, I is just one of the terms in the boundary condition. I_{tot} includes not only this "driving" sinusoidal flux, but upward thermal radiation and downward sky ratiation. Sensible heat transfer and evaporation also operate in parallel with radiation. Unfortunately, though all of these depend on temperature, none of them express a simple (but complex, in the sense of involving i) proportionality:

$$I_{tot} + H + LE = YT + I_{\uparrow}(T) + (-I_{\downarrow}(T)) + H(T) + LE(T)$$

The solution is to linearize the dependencies of these quantities, i.e. to assume for example that $I_{\uparrow}(T) = \frac{\partial I_{\uparrow}}{\partial T}\Big|_{To} T$ and so on. The constant term is removed by virtue of the linearity of the differential equation--it merely adds a constant amount to the mean temperature. Thus, we define an effective admittance:

$$I_{tot} + H + LE = T\,\{Y + \frac{\partial I_{\uparrow}}{\partial t} - \frac{\partial I_{\downarrow}}{\partial T} + \frac{\partial H}{\partial T} + L\,\frac{\partial E}{\partial T}\}$$

$$\equiv TY_{eff}$$

Since these functions depend on the instantaneous temperature they are real and independant on ω. They are:

$$\frac{\partial I\uparrow}{\partial T} = 4\varepsilon\sigma\bar{T}^3 \qquad (5a)$$

$$\frac{\partial I\downarrow}{\partial T} = 4\varepsilon_{sky}\sigma\bar{T}^3_{sky}\,\frac{\partial T_{sky}}{\partial T} \qquad (5b)$$

$$\frac{\partial H}{\partial T} = \frac{U_{*}k\rho K}{\ln(z/z_o - \Delta\psi_H)}\left(1 - \frac{\partial T_{air}}{\partial T}\right) \qquad (5c)$$

$$\frac{\partial E}{\partial T} = \frac{\partial H}{\partial T}\cdot\frac{1}{K_{air}}\,\frac{\partial S}{\partial T_{air}} \qquad (5d)$$

(k = vonKarman's constant, U_* = friction velocity z_o = roughness length, z = height of evaluation of T_{air}, $\Delta\psi_H$ = stability parameters, S = humidity).

The 'G factor' is the sum of these effective admittances, or some of them. Various authors use different symbols for it and include a different selection of terms. In any case, one gets

$$Y_{eff} = G + Y = G + \sqrt{\omega}\,p\,e\,\frac{\pi}{4} = (G + \sqrt{\tfrac{\omega}{2}}\,P) + i(\sqrt{\tfrac{\omega}{2}}\,P) \qquad (6)$$

$$T = \frac{1}{Y_{eff}} = \frac{A - iB}{(G + \sqrt{\frac{\omega}{2}}P) + i(\sqrt{\frac{\omega}{2}}P)} e^{i\omega t} \tag{7a}$$

$$= \frac{1}{(G + \sqrt{\frac{\omega}{2}}P)^2 + \frac{\omega}{2}P^2} \{(A(G + \sqrt{\frac{\omega}{2}}P) - B\sqrt{\frac{\omega}{2}}P) \cos(\omega t)$$

$$+ (-A\sqrt{\frac{\omega}{2}}P - (G + \sqrt{\frac{\omega}{2}}P) B) \sin(\omega t)\} \tag{7b}$$

$$= \sqrt{\frac{A^2 + B^2}{(G + \sqrt{\frac{\omega}{2}}P)^2 + \frac{\omega}{2}P^2}} \cos(\omega t - \tan^{-1}\left(\frac{B}{A}\right) - \tan^{-1}\left(\frac{\sqrt{\frac{\omega}{2}}P}{\sqrt{(G + \sqrt{\frac{\omega}{2}}P)^2 + \frac{\omega}{2}P^2}}\right))$$

in the three types of expression of the Fourier term. The solution to the heat equation for a realistic diurnal temperature curve may now be assembled by decomposing the solar flux into a series of harmonic terms and utilizing equation (7) to find the temperature variation due to each component.

Other Approaches to the Problem

Simplification of the boundary value problem for the heat equation to the point where an analytic solution in the form of Fourier series is feasible is not the only method in the literature. Three other approaches have been used.

Jaeger utilized Laplace transform methods to express the total heat flux out of a semi-infinite body (the ground) required for a given temperature profile to repeat itself periodically. He divided the period - the "day" - into a number of discrete intervals, and found the flux in the i^{th} period ϕ_i for a temperature of unity in the first period and zero in the others. Then a complete temperature curve could be built up by summing over a set of these temperature "pulses" of different strengths at different times:

$$F_i = \frac{P}{\pi} \sqrt{\frac{\omega}{2}} \sum_{j=1}^{20} T_j \, \phi_{i-j+1} \tag{8}$$

This is an expression for the flux in the i^{th} interval in terms of the temperatures in the other intervals T_j. The computation rests on the assumption that the fluxes for different temperature "pulses" may be summed, that is, that the problem is <u>linear</u>, the same assumption made in the fourier solution when harmonic terms of different frequencies were summed. In fact, the boundary conditions are nonlinear, but can be approximated by linear functions over the small temperature range within each time interval. The full boundary conditions yield a second expression for the fluxes in terms of the temperatures:

$$F_i = F(T_i) = I_i + I_\uparrow (T_i) + (-I_\downarrow (T_i)) + H(T_i) + LE(T_i) \tag{9}$$

Where, as above, the terms on the right are insolation, upward and downward longwave radiation, sensible heat transfer, and evaporative heat transfer. The thermal curve is computed by equating (8) and (9) for all F_i, and seeking the T_i for which the equality holds by some approximate methods.

A very different method which has been used by Rosema and Pratt, among others, is to attempt to solve the partial differential equation (1) with BC (2) by purely numerical means, using some particular differential equation solving algorithm. In general, the differential equation is converted to

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a difference equation by evaluating the temperature on a discrete lattice of times and depths. An initial temperature profile is specified, and an implicit or explicit finite difference relationship is used to generate successive profiles at each of the time intervals. The values at zero depth constitute the results of interest.

A full discussion of the numerical solution of the heat equation would be out of place here, but some of the advantages and disadvantages of the method may be outlined. Most significantly, any type of boundary conditions, linear, nonlinear, arbitrary, or a mixture of modeled and observed fluxes may be used with equal facility, similarly the soil properties need not be assumed homogeneous; an arbitrary profile may be modeled. As a final advantage, data are available in depth as well as at the surface. On the other hand, the choice of an algorithm, location of points in the vertical profile, and the choice of a time increment, represent a highly complex tradeoff between numerical stability, roundoff errors, and computation time. At best, numerical methods require far more computation than analytic ones. Furthermore, they yield only thermal curves for particular sets of physical parameters, whereas the fourier method, for example, yields a closed expression for the maximum variation in temperature as a function of thermal inertia and so on. The analytic methods deal with an implicit lower boundary condition $\frac{\partial T}{\partial t} \rightarrow 0$ as $z \rightarrow -\infty$, whereas an assumed temperature or geothermal flux must be specified at a finite depth in the numerical methods. An initial condition must also be explicitly specified. In practice, an estimate of the initial profile is made and the heat equation solved over a period of one day to obtain a better, "relaxed" estimate with which the computation of interest are made.

A final approximate method has been discussed by Deardorff. The heat equation (1) is split into two first order equations:

$$\rho \Delta z C \ \frac{\partial T}{\partial t} = - \ (F + G_{tot}) \tag{10a}$$

$$G = -K \frac{\partial T}{\partial t} \tag{10b}$$

where F and G_{tot} are respectively the non-conductive and conductive fluxes out of a small volume of material. F vanishes except at the surface, and

G_{tot} is the difference between the downward-directed fluxes G at the bottom and top of the volume. The thickness of material considered is z. Now, F is modeled analytically, as we have seen above. If G_{tot} at the surface could be modeled also, the second order partial differential equation(1) would be converted to a first order ordinary differential equation (10a) and solution would be relatively trivial. Deardorff discusses a number of such models, finding that of Bhumralkar and Blackadar to be the most effective. With T_{gfr} representing the ground surface temperature this method yields:

$$\frac{\partial T_{gfr}}{\partial t} = - c_1 F/(\rho Cd) - c_2 (T_{gfr} - T_2) \frac{2\pi}{\omega} \tag{11}$$

Here T_2 is the soil temperature at some depth d where it remains fixed on the time scale of a few days (a similar calculation may be done to find te effect of the annual temperature variation). C_1 and C_2 are constants; Bhumralkar sets $C_1 = 2\pi^{\frac{1}{2}}$ and $C_2 = 2\pi$ while Blackadar uses the values 3.72 and 7.4 respectively. Typical RMS errors for this method with respect to a full finite-difference solution of (1) were found to be close to 4% over a wide variety of soil and atmospheric conditions. The simplification involved in this method may thus be warranted by the great reduction in computation time with little loss of accuracy.

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